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JOURNAL OF THE AERONAUTICAL SCIENCES

Volume 5 DECEMBER, 1937 Number 2

Propellers for Aircraft Engines of High Power Output

FRANK W. CALDWELL, *Hamilton Standard Propellers*

Presented at the Annual Meeting of the Lilienthal-Gesellschaft für Luftfahrtforschung, Germany October 13, 1937

Reprinted Through the Courtesy of the Lilienthal-Gesellschaft für Luftfahrtforschung

THE trend in aircraft power plants during the last few years has been toward a sharp increase in the power output of each unit. This trend appears to be in response to the demands of airplane designers and operators, and the rate of increase of power output seems to be accelerating rather than tending toward a period of stability. This increase in power output is accompanied by a demand for higher altitude ratings and both of these requirements call for an extensive study of the propeller development which will be needed. In fact, the economic increase in engine size will soon be contingent on the progress of propeller development and it is the purpose of this paper to discuss some of the factors involved.

As a specific example of this trend there is considerable interest at the present time in the development of engines of large size with a power output of about 2000 hp. There is a simultaneous requirement for increased supercharging so that it is proposed to rate these engines at 20,000 ft. altitude. Due to the effect of the lower air density on the propeller characteristics, this would require a propeller of the same size as would be needed for 4000 hp. at sea level. In fact, the altitude propeller should properly be larger because the permissible tip speed is lower at high altitude due to the effect of the lower air temperature on the speed of sound. Since this size of engine will probably require a new type of propeller, it may be used as a basis for study. As there appears to be a requirement for such an engine to be rated at this power output at an altitude of 20,000 ft., the design may be studied with this rating also in view.

A theoretical three, four, and six-bladed propeller study was made, based upon the use of an engine having a normal rating of 2000 hp. at 2800 r.p.m. at 20,000 ft. altitude, and a one-minute take-off rating of 2300 hp. at 3000 r.p.m. at sea level. This engine, for purposes of computation, was assumed to have various reduction gear ratios ranging from 0.5 to 0.3. Each of these engines was considered installed in each of four airplanes, having successively greater maximum speeds at 20,000 ft. of 250, 300, 350, and 400 m.p.h.

A three, four, and six-bladed propeller was selected for each airplane-engine combination. Each propeller was assumed to have blades of normal planform and to be of the conventional Hamilton Standard construction: solid aluminum alloy blades in a steel hub.

The diameter of each propeller was selected from an empirical formula for three-bladed propellers which is based upon N.A.C.A. test data. This formula expresses the optimum diameter as a function of engine power, altitude of operation, propeller rotational speed, and airplane forward speed. Because of the complicated combined effect of several propeller parameters upon this diameter, it can be said that this relation only holds when the propeller's blade planform, thickness, and airfoil section have certain fixed dimensional ratios, and when the effective tip speed is low enough so as not to have an effect upon propulsive efficiency. All the propellers of this study, therefore, are hypothetical to

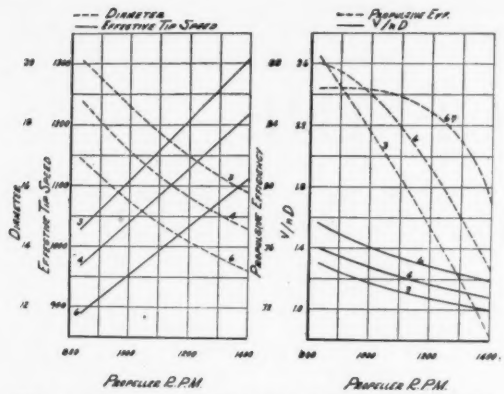


FIG. 1. Effect of diameter and r.p.m. on the propeller efficiency for an airplane having a maximum speed of 250 m.p.h. and using 2000 hp. in each propeller at an altitude of 20,000 ft. Three, four, and six blades are considered.

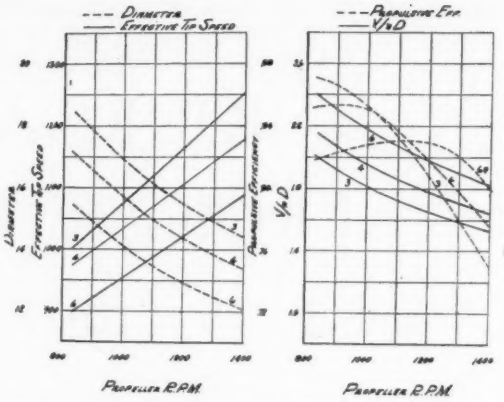


FIG. 3. Effect of diameter and r.p.m. on the propeller efficiency for an airplane having a maximum speed of 350 m.p.h. and using 2000 hp. in each propeller at an altitude of 20,000 ft. Three, four, and six blades are considered.

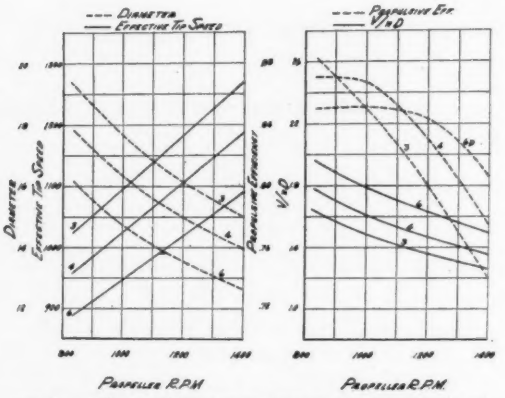


FIG. 2. Effect of diameter and r.p.m. on the propeller efficiency for an airplane having a maximum speed of 300 m.p.h. and using 2000 hp. in each propeller at an altitude of 20,000 ft. Three, four, and six blades are considered.

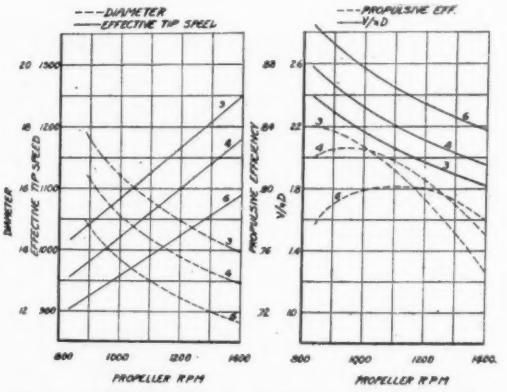


FIG. 4. Effect of diameter and r.p.m. on the propeller efficiency for an airplane having a maximum speed of 400 m.p.h. and using 2000 hp. in each propeller at an altitude of 20,000 ft. Three, four, and six blades are considered.

the extent that, regardless of diameter, they have been assumed to be geometrically similar and dimensionally chosen to fall within the limitations of the empirical formula. The one parameter, effective tip speed, is an exception in that it was neglected in the selection of diameters, but it was taken into account when propulsive efficiencies were computed. Effective tip speed, incidentally, is the actual tip speed of the propeller corrected for the effects of air temperature, *i.e.*, altitude, blade thickness, and angle of attack. The actual tip speed of the propeller in itself, it has been found, is not a satisfactory measure of the loss in propulsive efficiency.

For the four-bladed propellers, the empirical formula for the three-bladed diameters was employed but, in place of the full-rated b.hp., a value three-fourths as great was used. Similarly, for the six-bladed propellers, the same formula was used but with a value of one-half the rated b.hp.

The efficiency and static thrust computations were based on a system developed by the United Aircraft Corporation. Basic data and the effects of pertinent parameters, given by this system, have been based upon an accumulation of all the reasonable wind-tunnel model, test stand, and full flight data made available by the various research organizations in the world. Naturally, since the data of this type available on four and six-bladed propellers are so very limited, this system has only been developed for two and three-bladed propellers. The efficiencies, therefore, of the four and six-bladed propellers include the corrections for all the losses found experimentally for three-bladed propellers with the exception of the race rotation and slipstream velocity losses, which have been replaced by some calculated theoretically for the larger number of blades. It is believed that the other losses of the four and six-bladed propellers will not differ from those determined experimentally for the three-bladed propeller by an order of magnitude greater than the reasonably expected experimental error. A somewhat similar situation holds for the static thrust computations for four and six-bladed propellers in that certain corrections were assumed to be the same regardless of the number

TABLE 1

$V_{max.}$	m.p.h.	250			300			350			400		
	km./hr.	402			483			563			644		
Number of Blades		3	4	6	3	4	6	3	4	6	3	4	6
Optimum Diameter	ft.	21.0	18.0	15.0	19.5	17.0	14.0	18.5	16.5	13.5	18.0	15.5	13.0
	m.	6.40	5.48	4.57	5.94	5.18	4.27	5.63	5.03	4.12	5.48	4.72	3.96
Propeller Weight	lbs.	1400	1200	1050	1150	1000	850	975	925	775	900	775	700
	kg.	635	544	477	522	453	386	443	420	.	408	352	317
Gain over Six-Bladed	η%	2.5	1.5	...	4.0	2.0	..	4.0	2.5	..	4.0	2.5	..

TABLE 2

Maximum Speed of Airplane	m.p.h.	250			300			350			400		
	km./hr.	402			483			563			644		
Number of Blades		3	4	6	3	4	6	3	4	6	3	4	6
Static Thrust	lbs./engine	10,100	8900	7700	9600	8700	7200	8700	8300	6800	8100	7200	6300
	kg./motor	4590	4040	3500	4360	3950	3270	3950	3770	3090	3680	3270	2860

of blades, while others were theoretically altered for the different propellers.

For the total propeller weight estimates, the three-bladed propeller was assumed to vary from actual known weights as the cube of the diameter. For the four-bladed propellers, one-third was added on to these three-bladed weights, and for the six-bladed the three-bladed weights were doubled.

The computations indicate that for constant speed propellers operating at 20,000 ft. and absorbing 2000 b.hp. at forward airplane speeds of from 250 to 400 m.p.h., the engine should be so geared that the propeller will turn, at rated engine speed, at approximately:

800 r.p.m. for three-bladed propellers
925 " " four-bladed "
and 1150 " " six-bladed "

For each of the four airplanes with engines whose gear ratios result in the above propeller r.p.m., maximum propulsive efficiency is obtained. Table 1 shows, for each airplane so equipped, the optimum diameter, expected propeller weight, and comparative propulsive efficiency of the three, four, and six-bladed propellers.

Using these optimum diameters, the static thrust figures obtained with 2300 hp. at sea level at engine speeds approximately 10 percent greater than those listed above are given in Table 2 for each airplane.

The detail results of all computations are plotted in Figs. 1, 2, 3, 4, 5, and 6.

The requirements of particular airplanes of the general characteristics of those studied herein will dictate, to a large extent, the number of blades that should be used. The summary of the general results listed above indicates that the three and six-bladed propellers each have decided, particular advantages, and that the four-bladed propellers represent a good compromise of the characteristics of the three and six-bladed models. The six-bladed propeller has two very important advantages over the others, those of optimum diameter and weight. In general, it requires 17 percent less diameter than the four-bladed and 28 percent less than the three-bladed. The method used to estimate weights results in approximately a 10 to 17 percent advantage for the six-bladed over the four-bladed, and a 20 to 26 percent advantage over the three-bladed. Offsetting these decided advantages are the lower propulsive efficiencies of the six-bladed propeller, shown in Table 1, and a gain of about 23 percent of static thrust of the three-bladed over the six.

If an engine of the type studied were installed in a transport or bomber having a maximum speed of 250 m.p.h. at this altitude, the corresponding propeller diameter would be about twenty ft. On the other hand, if such an engine were installed in a small plane having a maximum speed of 400 m.p.h., it would be possible to use a six-bladed propeller with a diameter of twelve ft. six in.

A simple examination of the characteristic aerodynamic and geometric relations of the propeller indicates that for geometrically similar propellers operating at the same tip speed the weight per horsepower is proportional to the diameter divided by the relative air density.

The advantages of controllable pitch and constant speed propeller operation are so great that it seems certain that these features will be necessary for the large engines. While there is no great aerodynamic gain in feathering the propeller, it seems probable that this feature may be required to stop the rotation of inactive engines. In order to incorporate these features we must compare future weights to those of existing successful propellers in the current sizes. The present Hamilton Standard controllable pitch propellers show a ratio of weight (lbs.) to diameter (ft.) cubed of about 0.2, see Fig. 5. Optimistically, we might hope to reduce this ratio to about 0.15 by design refinements in the very large sizes. Even this figure, however, would lead to a propeller weight of about 1200 lbs. for the 2000 hp. propeller at 20,000 ft. altitude, since the aerodynamic requirement calls for a diameter of about 20 ft. The propeller weight in lbs. per hp. would then be

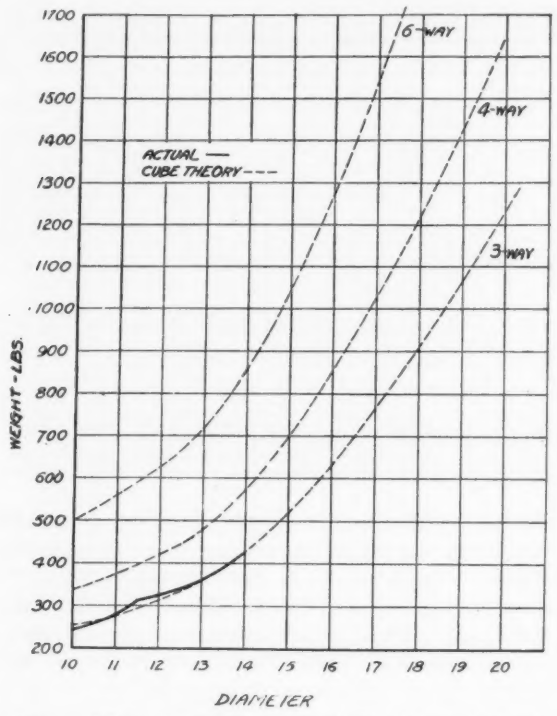


FIG. 5. Effect of diameter on the weight of three, four and six blade propellers.

about 0.6 in comparison to the present figure of 0.35. The propeller weight will, of course, become even more unfavorable as the engine power increases beyond 2000 hp. and it will be advantageous to design the aircraft and power plant with a greater attention to providing favorable conditions for the propeller.

Since the vibration conditions determine the propeller design to a large degree, the most serious problem will be to isolate the propeller as far as possible from serious sources of vibration. It will not be sufficient to provide smooth torque through dampers, flexible drives, and the like, but the propeller must be insulated from excitation along and about all three axes. Up to the present time, the propeller-design problem has been one of fitting a suitable propeller to an engine and airplane combination which had been established more or less independently of propeller characteristics. Under these circumstances and in order to have a propeller design capable of reasonably extensive application, it has been necessary to attempt to build propellers of sufficient strength so that they would be capable of resisting very excessive vibratory excitations and so that they would not fail regardless of abuse in the way of applications and service operations.

As pointed out above, the design requirements for the propellers for these large engines will lead to a very great increase in propeller weights if the present design practice is adhered to. These weights are apt to be so great that it will no longer be good practice to ask the propeller designer to fit a propeller to an independently developed engine and airplane combination, since the overall weight probably will be favored by a design which will permit favorable conditions for the propeller. Whether the propeller for the large power plants of the future will be one of very great diameter with a high reduction from crank speeds, a multiple-blade design of a somewhat higher rotational speed, or some type of counter-rotating propeller, will depend on a number of factors involving propeller efficiencies, weight complications, the permissible clearances of aircraft structure, as well as considerations of vibratory stress. Whichever line of development is followed, it appears very probable that it will be most advantageous to insulate the propeller from the engine as thoroughly as possible, since the types of excitation are so varied and of such severe magnitude that it appears almost impossible to design away from them in the propeller structure itself.

In view of the great weight of the large three-bladed propellers, it appears desirable to consider three phases of the propeller development:

(a) Large propellers having a diameter of twenty ft. for bombers and transport airplanes.
(b) Six-bladed hubs for small airplanes.
(c) The counter-rotating propellers.

At this point, attention should be called to the fact that a different gear ratio will be required for the six-bladed propeller from that needed for the three-bladed propeller. If the same gear ratio were used for both, the six-bladed construction would be very much heavier and would only lead to a reduction of diameter of about 15 percent.

The three-bladed propeller can best be used with a gear ratio which leads to the maximum permissible tip speed when the diameter and area of the blades are properly fitted to the engine and airplane characteristics. The gear ratio for the six-bladed propeller should be a different one and so selected that the propeller tip speed will again be the maximum permissible when the diameter and blade area are properly fitted to the engine and airplane requirements.

The case of the large propeller for transport and bombers seems fairly straightforward as to objective, as this development is in response to a well-defined demand. The large propeller of twenty ft. diameter could be developed along the present lines using the forged aluminum alloy blades and the steel hubs. However, the weight would be excessive, a figure of 1200 lbs. being indicated by the study. This would correspond to a weight of 0.60 lbs. per hp. against the current figure of about 0.35 for the 1000 hp. engines. Consequently, the problem becomes primarily one of reduction of weight while maintaining a satisfactory stress condition.

The first move toward a reduction of propeller weight

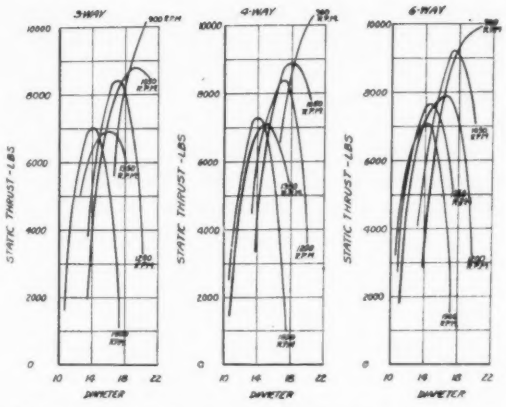


FIG. 6. Effect of propeller diameter on static thrust of three, four, and six-blade propellers absorbing 2300 hp. for take-off.

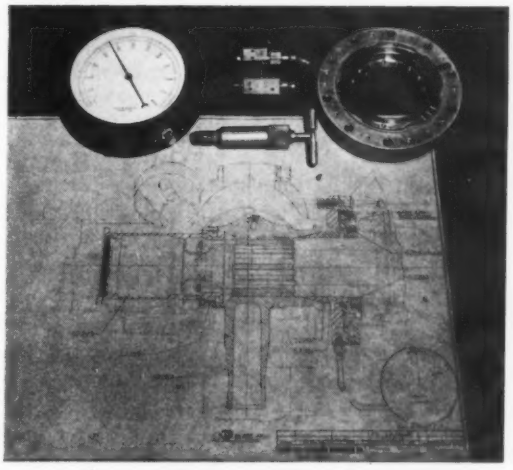


FIG. 7. The propeller thrust meter is serving a useful place in measurement of propeller thrust at low air speed and in more accurate determination of the effect of altitude on the compressibility burble.

should be insulation against the abnormally severe vibratory excitation introduced by the engine. One method of accomplishing this result would be to mount the propeller in an independent outboard bearing which could be suitably insulated from vibration. At the same time, the drive would have to be designed for extreme flexibility combined with proper damping. If we remove the most severe sources of excitation, we could probably design a propeller to a weight about one-third less than the current figure so that the weight per hp. could be brought down to about 0.42 which would not be an unreasonable comparison to the present figure of 0.35. The present thought is that the most promising line of weight reduction would be through the use of solid blades made of an alloy of magnesium or through the use of semi-hollow blades made of aluminum alloy.

In the case of the magnesium alloy, an effort would probably be made to use aluminum alloy parts in the hub. The principal experimentation in this case would be directed toward adapting the design to the peculiar properties of these materials. Fortunately, our metallurgical friends have made a great deal of progress in learning the characteristics of this metal and can now furnish material with good mechanical properties and a high degree of integrity. We have very great appreciation of the efforts of I. G. Farbenindustrie in taking the lead in this work.

As an alternative to the use of the light metals, a great deal of attention will undoubtedly be given to the use of hollow steel construction, either of the welded or of the pressed tube type. The vibration problem in connection with the hollow steel type, however, will be more complex due to the necessary use of thin walls which may lead to independent vibrations of small portions of the structure. The plastic materials will also be developed and there appear to be certain possibilities of weight reduction in the use of some of these materials. In appraising the final design, however, it will be necessary to take account of the fact that blades of these materials may have to be thicker than the metal blades so that the efficiency may be somewhat lower. A very practical objection in practice may come from the fact that these materials have no ductility so that they disintegrate in a dangerous manner in a minor airplane accident; whereas the metal blades are bent out of shape but do not fly apart.

INCREASE IN THE NUMBER OF BLADES

In addition to the use of a three-bladed propeller of large diameter, consideration has been given to the use of a larger number of blades. For the example which I have chosen to discuss I have made some studies involving the use of four and six blades.

If a new gear ratio is chosen for the six-bladed propeller, its tip speed may be made about the same as that of the large three-bladed propeller and there will be a material reduction in weight. In fact the weight per hp. for the two-thousand hp. engine becomes comparable to the figure for the present one thousand hp. propellers which we are now building. Naturally, the six-bladed propeller will have a somewhat lower efficiency than the three-bladed one due to higher slipstream velocity and, consequently, greater momentum losses. This drop in efficiency is of the order of magnitude of 4 percent at the V/ND ratios in which we are interested and this would not be prohibitive in certain types of aircraft where the saving in weight of the propeller and the reduction in airplane drag due to more compact design permitted by the smaller propeller diameter might outweigh the loss in propeller efficiency. For long range aircraft, however, a loss of four percent in propeller efficiency is very serious because of the importance of fuel consumption.

Of far more significance for long range aircraft is the loss of static thrust, (see Table 2), which has a large influence on the take-off characteristics of the airplane.

The loss in static thrust may be as great as 30 percent for the six-bladed propeller and since the long range aircraft are apt to be of a type where take-off is difficult at best it seems unlikely that such a low static thrust can be tolerated. This loss of static thrust is mainly due to increase in slipstream velocity and is an inescapable result of the smaller diameter. Due to the severe static thrust loss, it appears improbable that the six-bladed type would be acceptable for large airplanes of the bomber or transport type.

For small planes, with relatively low power loading, the sacrifice in take-off should not be a serious consideration and the loss of 4 percent in efficiency at top speed does not appear prohibitive. When these losses are set against the saving in propeller weight and advantage of a moderate propeller diameter, the six-bladed type looks attractive for the smaller planes.

The question as to whether the six-bladed or the counter-rotating system should be worked out for the small planes will depend on the degree to which the propeller torque is prohibitive in connection with small planes equipped with large engines. If it is impractical to take care of the torque there would be little use for the multiple-blade propeller. A solution of this question is important from the propeller designers' point of view. The only experience with single engines using 2000 hp. in small planes that we know of was had in connection with the Schneider Cup racers. In this case the torque is said to have been very critical and unsatisfactory. It should be borne in mind, however, that the Schneider Cup racers did not have controllable pitch propellers so that full torque had to be used for take-off. Also the torque situation will be helped by the use of multiple blades since the smaller diameter propeller will permit higher r.p.m. and, consequently, lower torque.

It is probable that very favorable propeller conditions for take-off would occur if the constant speed type with ample pitch range is used. By holding to maximum r.p.m. and using only about 1400 hp. for take-off, it is possible that the take-off may be satisfactory for military service. In this case, the torque would not be much worse than with the current engines, which are rated at 1400 hp. for take-off. An alternative way of avoiding the torque would, of course, be the use of two smaller engines designed for opposite rotation, or the use of a single engine with a gear drive to a propeller on each wing.

The design of the six-bladed controllable pitch hub will be primarily a problem of adapting the hub to accommodate six more or less conventional blades. However, complete insulation from vibration should make it possible to use smaller shanks than normal, resulting in a material reduction in hub weight. To determine how far we can go in this direction will involve a fairly extensive program in the way of design testing and stress measurement.

The curves of Fig. 1 indicate that a diameter slightly over fourteen ft. would be required for the six-bladed case if the top speed were taken at 250 m.p.h. and tip speed limited to 1030 ft. per sec. For the 400 m.p.h. airspeed, however, a diameter of 12 ft. 6 in. appears sufficient and this could be compromised to twelve ft. without serious loss in flight efficiency. The corresponding weight should be of the order of magnitude of 700 lbs., corresponding roughly to present weight per hp.

Counter-Rotating Propellers

The principal advantage of the counter-rotating propeller appears to be in the elimination of the torque reaction in a single-engine airplane of relatively small size. There is a small gain due to elimination of the race rotation in the slipstream. The momentum theory indicates that this may be of the order of one percent. Wind-tunnel tests appear to show a slightly greater gain. The counter-rotating propeller is subject to the same objection as the multi-bladed propeller in that the sacrifice in take-off thrust would be serious. This may not be vital for small aircraft, but it will be of the greatest importance for aircraft designed for carrying heavy loads such as transport bombers, etc.

While the counter-rotating propeller shows a better efficiency than the six-bladed propeller, it is inferior to the large three-bladed propeller and it appears unlikely that the use of this device could be tolerated on planes of the load-carrying type. One serious objection to the counter-rotating propeller scheme is the introduction of a new and additional source of excitation of propeller vibration. Our thought has been that we should design away from excitation in various ways. Just how serious this problem will prove cannot be estimated without an extensive series of experiments. It would appear unwise to rely too much on the success of the counter-rotating scheme until this point has been determined. Experience with the device in recent years has been confined to the Fiat propeller for the racing planes. While these propellers were certainly well adapted to the intended purpose, they were not operated long enough to learn about the cumulative effects of vibratory stresses which might lead to fatiguing of the blades.

The counter-rotating propeller also involves a serious mechanical engineering problem in the design of the gearing and the mounting of the propeller shafts as well as in the design of the pitch-changing gear. These latter problems can undoubtedly be worked out by exercise of ingenuity and expenditure of sufficient effort in development. In view of the number of questions involved in the counter-rotating development, my judgment would be that this should be treated as a type of development which would involve a major undertaking. Even under present conditions, it is almost impossible to be sure of the safety of propellers and we do not yet know of any test procedure to give assurance of satisfactory safety

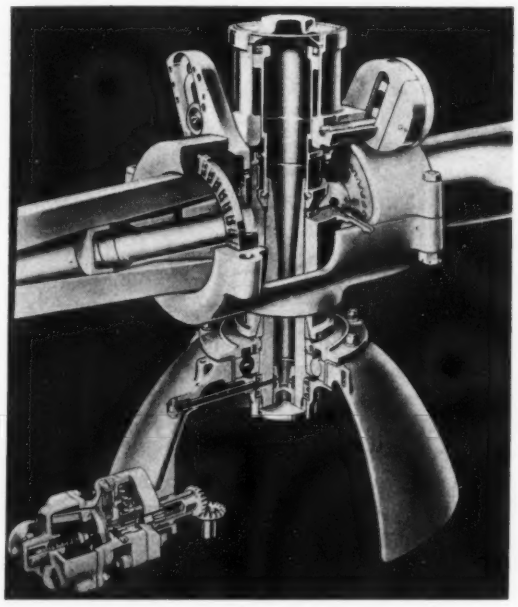


FIG. 8. Typical Hamilton Standard controllable pitch propeller and constant speed control assembly.

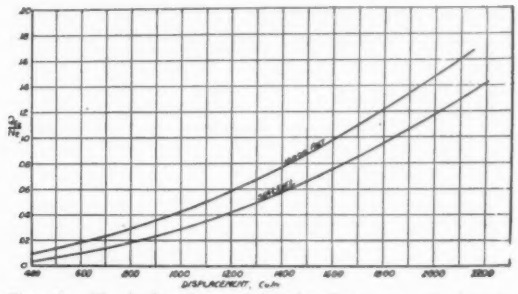


FIG. 9. Typical values of frictional torque of aircraft engines in terms of displacement.

$Q_{fe}/N_e = \Delta(0.3\Delta + 0.0143h - 6)10^{-7}$

Q_{fe} = Engine torque, lb. ft.

N_e = Engine r.p.m.

Δ = Displacement in cu. in.

h = Altitude in ft.

of the counter-rotating type. It would appear extremely desirable from the standpoint of aircraft safety, which is very important even for military aircraft, that any system of counter-rotating propellers should be subjected to the most rigorous series of tests before it is put into service. On account of the difficulty of predicting fatigue effects, these tests should probably be extended over a period of several years.

CONTROLLABLE PITCH AND CONSTANT SPEED PROPELLERS

The advantages and manner of operation of the controllable pitch propellers are now so well known that it hardly appears necessary to discuss this subject. However, the constant speed propeller is not yet so widely used in Europe as in America, and it may be worth while to outline in a few words the reason leading up to the development of this type and some of its characteristics in operation.

The introduction of the original Hamilton Standard controllable pitch propeller permitted the pilot the option of two pitch settings and thereby solved the problem of avoiding the inefficient conditions for propeller thrust during take-off of modern high-speed planes which usually are equipped with propellers of high pitch for conditions of maximum speed and cruising. This high pitch leads to a loss in thrust during take-off due to two causes: first, because the propeller characteristics were such that the engine could not turn up to its rated speed and there was, consequently, a loss in engine horsepower; second, the high pitch angles resulted in an extremely low propeller efficiency. Both of these conditions could be improved by the use of a lower pitch angle during take-off and the practical aspects of the problem were solved in a simple manner by the use of a propeller which permitted two alternate pitch settings. The two alternate pitch settings were still compromise settings, however, and since the mechanism for changing the pitch in flight had already been worked out, it was thought desirable to introduce a further refinement which would provide for a continuous selection of pitch to meet the varying conditions of flight.

Some of the factors which have to be taken into account in selecting a proper pitch setting for the propeller are: forward velocity of the airplane; rate of revolution of the engine; b.m.e.p. of the engine; fuel consumption of the engine; density of the air; efficiency of the propeller, etc. Since all of these factors are changing rapidly in flight and since a rather involved calculation would be required for each pitch selection, it seemed hardly practical to ask the pilot to take on the additional duty of selecting the pitch and adjusting the propellers. This was particularly true where airplanes with multiple engines were concerned and the condition was especially difficult during take-off and during the maneuvering of fighting planes. It therefore appeared highly desirable to provide some automatic device to carry out the pitch changes which had to be made rapidly but to leave the pilot some control over the automatic device for major changes in the conditions of flight.

A large number of different systems of automatic pitch variation were considered and it was finally decided to adopt the scheme of maintaining the rate of revolution of the engine constant by means of changes in the pitch of the propeller. This system was particularly desirable with the Hamilton Standard type of propeller because the oil supply controlling the pitch of the propeller could be regulated by a precision type of governor in which the speed could be established by the pilot by a simple control of the pressure on the governor

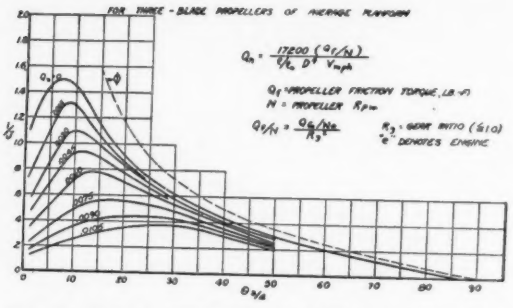


FIG. 10. Values of ND/V for windmilling propellers driving engines with various torque coefficients. (ϕ = angle of advance.)

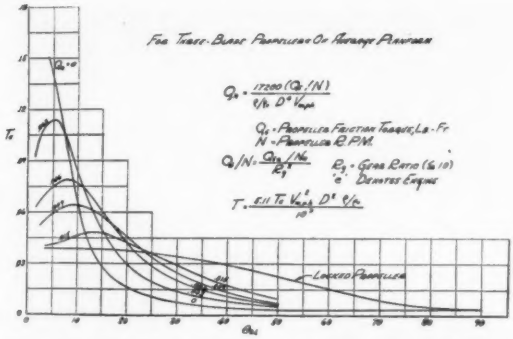


FIG. 11. Negative thrust or resistance of windmilling propellers at various torque coefficients.

spring. The precision of this governing system had to be so great as to permit the pilot to synchronize the various engines of a multiple-engined airplane and to maintain synchronism for various conditions of flight after it was once established. The constant speed principle of operation appeared to be the only one capable of fulfilling these requirements and it was adopted for the Hamilton Standard development. (See Fig. 8.)

Aircraft engines are usually rated with a certain allowable maximum rate of revolution for maximum power output. When the airplane is to be operated at maximum performance such as at take-off or for certain maneuvers, the constant speed control is set for maximum revolutions and need not again be adjusted by the pilot. The control unit will automatically maintain the engine at precisely the required speed without further attention regardless of the speed of the airplane, of the changes in air density, etc. When a different type of performance such as cruising is desired, the pilot again adjusts the control unit for the desired performance and no further attention is required. This principle of operation has proven so satisfactory in engines of the present sizes, that it appears that it will certainly be required in the large power plants of the future.

A theoretical objection against the constant speed principle has been raised on the ground that the speed of revolution is controlled by changes in angle of incidence of the propeller blade so that the incidence must depart from the optimum value under some conditions of flight. Fortunately, the angle of incidence may be varied over quite wide limits without material change in efficiency so that there is no appreciable loss from this source in practice. The advantages of the constant speed principle are now made use of in a very extensive way in the field of commercial flying. It probably has an even greater advantage for military aeronautics in making available full engine power during rapid maneuvers and in preventing abuse of the engine in diving by holding the engine speed to its rated value.

THE CASE FOR THE FEATHERING PROPELLER

A great many exaggerated statements have been made in regard to the advantages to be had from the expedient of feathering propellers on engines which are not running during flight. The use of this procedure has been advocated for aircraft with multiple engines, since it was claimed that the performance with one engine out of commission could be improved greatly by adjusting the pitch of the blades so that the chord of the airfoil was subtantially parallel to the line of flight. A closer examination has shown, however, that this is only true for aircraft of low performance where the pitch angles of the propeller blades are very low. If the pitch angle at the three quarter radius exceeds 30°, the gain is extremely small, and for settings in excess of 35°, we have not been able to measure any difference in performance between the feathered propeller and the windmilling propeller. (Figs. 10 and 11.) However, it may be necessary to stop the rotation of an engine in flight due to breakage of certain parts which might cause dangerous stresses if rotation of the engine were allowed to continue. If the rotation is stopped by means of a brake, the resistance of the propeller is greatly increased and there is some loss in airplane performance due to this increased resistance. The rotation of the engine may be stopped by feathering the propeller without loss in performance. Consequently, the utility of the feathering propeller should be considered from its value as an efficient brake which permits the engine to be stopped without loss in performance and not as a device which leads to any improvement over the performance of propellers operating in the conventional manner.

At one time it was proposed to make use of the feathering procedure on multiple engine aircraft of long range where the engines would be run at thirty to forty percent of maximum power. For this type of aircraft it was thought that the propellers on some of the engines could be feathered to stop rotation of the engine and to provide a minimum drag for the propeller and that the remaining engines could then be run at a somewhat higher power output with a view to improving their specific fuel economy. The constant speed propeller with the large variation of pitch angle now used makes it possible to operate the engines at the best combination of speed of rotation and mean effective pressure

for low specific fuel consumption even at very low power output. Hence, there is no advantage in stopping part of the engines from the point of view of fuel economy and this proposed use of the feathering device does not appear desirable The feathering device, therefore, has no useful purpose for normal operation and is to be considered as a safety device designed to protect the aircraft from damage due to the vibration of broken parts in the engine. While eliminating this hazard, the feathering practice introduces new hazards due to the possibility of malfunctioning or due to errors on the part of the pilot. Any design of a feathering propeller should incorporate features to minimize these risks as otherwise the new danger may be greater than the old one. It appears that there is a fairly clear case for the feathering propeller on long range commerical flights such as the transatlantic crossing where emergency landings are impossible. The case is not so clear for short range commercial flights or for military aircraft.

Reversing the Propeller Pitch as a Means of Shortening the Landing Run

Aircraft of large size have to be very clean aerodynamically both from the standpoint of speed and from that of cruising economy as it affects long range. At the same time the wing loading continues to increase so that landing speed and tendency to float in landing would already be beyond permissible limits except for the use of flaps and other spoiling devices and, of course, the wheel brakes. Even with the spoilers and brakes it seems that we are approaching a size of aircraft where the available landing area will be insufficient so that some additional retarding mechanism may be needed.

It has been proposed that the pitch of the propeller blades might be shifted into such a range as to give a negative thrust and thus provide a very powerful brake. Wind-tunnel tests have indicated that the reverse thrust of the propeller under these conditions is several times the forward thrust under normal conditions so that it is possible to exert a deceleration of about one-half in certain cases. Practical flight tests made a number of years ago on aircraft without wheel brakes indicated that the propeller with reversed pitch cut the landing run to about one-third of the original value.

There is no doubt that the use of the propeller as a landing brake would be very effective. There are, however, certain hazards in its use, as improper operation or malfunctioning would be apt to lead to an accident. It is nevertheless not possible to drop the propeller with reversing pitch from consideration and it may be that the large airplane of the future will have to make use of this principle. Certainly a propeller designed for this purpose would have to operate with very great rapidity and the pitch adjustment from forward to reverse and back to forward position would have to be carried out positively and infallibly.

Methods of Assuring the Safety of the Propeller

Probably the most difficult problem in connection with the propeller is the matter of determining its safety before it is put into service. We cannot afford to follow the method of trial and error since a propeller failure is of such serious consequence that it may cause loss of life and since a number of failures may occur on a given type of aircraft and engine before the proper corrective action can be determined. It is, therefore, of the greatest importance to set up some criterion for safety of a propeller of a new type. We have worked along a number of lines to reach a satisfactory criterion and in fact this is the greatest problem confronting the propeller designer. The following are some of the methods which we have used for this purpose:

(1) The method of statistical comparison by which the service record of a large number of satisfactory propellers is compared and an effort is made to predict the safety of the new design by analogy. The propeller stress problem is so complicated and our knowledge is so limited that this method has been most valuable in the past and, no doubt it will continue to be so in the future. This method has the disadvantage that it does not permit wide departures from current types. Progress in engine and aircraft design is now so rapid that the value of the statistical method is being greatly reduced.

(2) Calculation of the static and elastic stresses in the propeller. These calculations should, of course, be carried out as a routine procedure. However, they only serve to eliminate the most glaring faults in the design and they are of comparatively minor value in respect to prediction of fatigue failures.

(3) Overload tests on whirling stands. In the past, these tests have been carried out with electric motors with smooth torque. These tests have served a very useful purpose in the study of flutter, etc., but have not been satisfactory in predicting fatigue effects. It is now proposed to combine the whirling test with some device for artificially exciting a controlled amplitude of vibration.

(4) Engine tests of short duration at overload power. This type of test is probably the most useful single test but it is difficult in practice on account of the rapid destruction of the engines used for testing.

(5) Engine tests of long duration at normal power. It is practically impossible to use this type of test on account of the time and expense involved. Many propellers are now used in service for 4000 hrs. to 6000 hrs. so that more than a year would be required for a single test.

(6) Examination of critical vibration periods to establish the possibility of resonance. This method is now followed as a routine and will undoubtedly be of

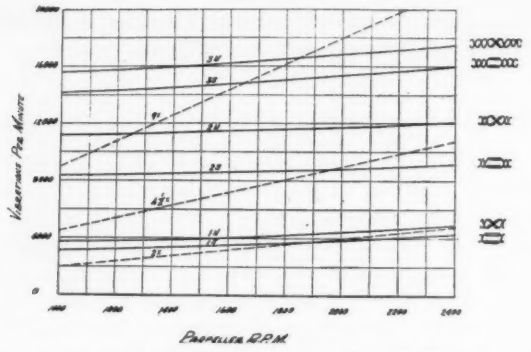


FIG. 12. Static vibration frequencies corrected for centrifugal force. Blade design 6095–6.

Correction Factors for the Effect of Centrifugal Force on Various Types of Flexural Vibrations:

$$(f_R = \sqrt{f_o^2 + cN^2}\ )$$

Type of Vibration	c (Theodorsen)	c (Hamilton Standard)
	1.7	1.5
	2.34*	
	6.2	6.2
	-	-
	12.2	12.2
	8.73*	8.9

*These values are calculated by the method advanced by Theodorsen.

FIG. 13. Effect of centrifugal force on natural frequencies of rotating propeller blades.

more value when we have learned to interpret the results. The non-rotating propellers are excited at their various frequencies and corrections are applied for the effect of centrifugal force. These frequencies are then compared to the known sources of excitation as to the possibilities of resonance.

(7) Methods of determining the actual occurrence of resonance vibration in the rotating propeller. These methods include the use of stroboscopes, both mechanical and luminous, the use of mirrors, instantaneous photography, etc.

(8) Measurement of engine excitation. As a routine matter, the torsional periods in the crankshaft system are now measured. This procedure is being amplified by measurements of the motion of the engine along and about the three axes in space. This data is of very great value to the propeller designer.

(9) Measurement of vibratory stress in the propeller. All of the other criteria and methods of test are aimed at determining whether conditions are present which might cause high vibratory stresses in the propeller blades. If these vibratory stresses are measured directly, an extremely valuable criterion of safety can be developed.

We have had a great deal of experience with testing of propellers on various test stands driven by electric motors. We are usually able to run the propellers at an enormous power input on these stands without damage. A propeller of the same design often fails after a short run on an internal combustion engine of comparatively low power. An example of such a condition is a small propeller with a diameter of nine ft. having magnesium alloy blades. This propeller was designed for use on a seven-cylinder air-cooled radial engine having a power output of 225 hp. This small propeller was subjected to various overload tests being run on the electrically driven stand for ten-hour periods successively at 600 hp., 800 hp., 1000 hp., and 1200 hp. As the propeller showed no signs of distress at the end of this testing, it was then run for one-hour periods successively at 1300 hp., 1400 hp., 1500 hp., 1600 hp., and 1700 hp. At the end of the 1700 hp. period the propeller was found to have a small crack through a deep nick near the tip caused by striking a stone early in the test. The inner portion of the blade showed no distress whatever.

As this test indicated a considerable margin of reserve strength, an exactly similar propeller was subjected to a proof test on the 225 hp. engine. After two hours of running on the engine, one blade broke at a point near the hub. An examination of the fracture showed clearly the effect of fatigue caused by repeated stresses. This case was not an isolated example but was typical of many other tests carried out before and after. Obviously, the repeated stresses could only be caused by some condition of vibration and the great discrepancy in power loading conditions caused us to look for some kind of resonance in the propeller blades and an attempt was made to compare the frequencies of the various kinds of excitation with the frequencies of the natural periods of the blades for different modes of vibration. (See Fig. 12.)

As there are many sources of excitation and the energy of excitation is very great, it seemed that all propellers should break if this were the cause of failure. An examination of the stress distribution corresponding to the modes of vibration which we were able to identify and excite readily showed that all of these modes produced high stresses in the outer parts of the blades but extremely low stresses near the shank where the failure occured. Therefore, it appeared very unlikely that any of these modes could be causing the failures near the hub of the propeller.

We have been unable to excite a form of vibration where the propeller is vibrating in the plane of maximum stiffness of the blade section. It may be that the action of centrifugal force in increasing the stiffness of the propeller in the more flexible direction could tend to make vibration in the plane of maximum stiffness more pronounced. Since the centrifugal constant is much greater than the elastic constant, stiffness in the two directions would differ much less in the rotating

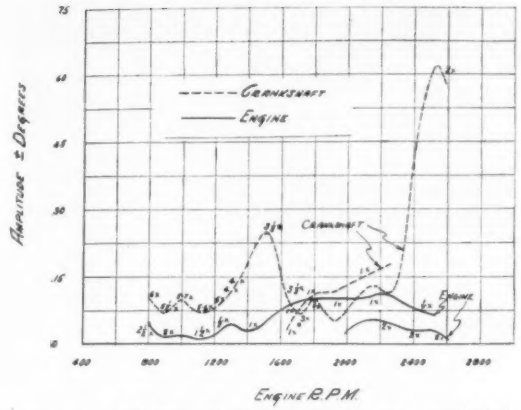


FIG. 14. Torsional vibration of engine and crankshaft for an experimental 1400 hp. engine driving through a .5 reduction gear a three-blade controllable pitch propeller with a diameter of 12 ft. 6 in. (Measurements taken with M.I.T. electromagnetic velocity type torsiograph.)

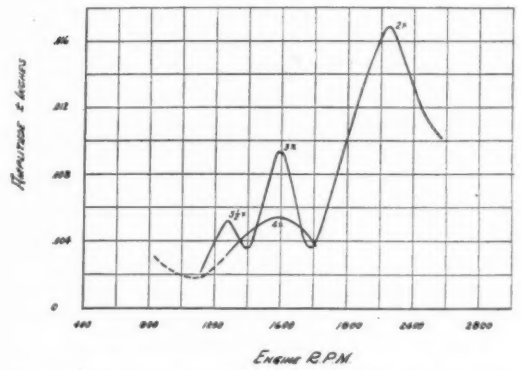


FIG. 15. Amplitude of vertical vibration of engine nose.

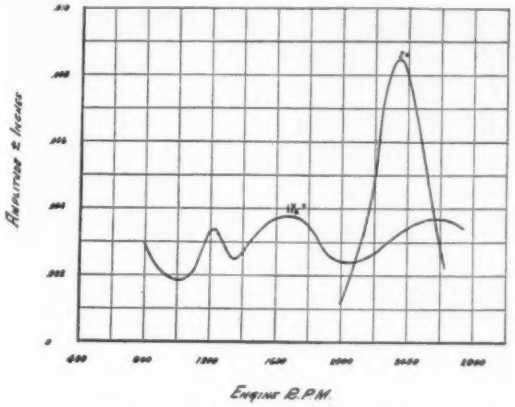


FIG. 16. Amplitude of fore and aft vibration of engine nose.

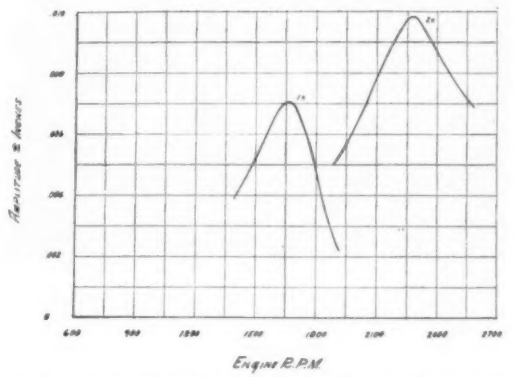


FIG. 17. Amplitude of lateral vibration of engine nose. (Measurements taken with M.I.T.-Sperry linear electromagnetic pick-up.)

propeller. (See Fig. 13.) If blade resonance were to occur with the blade vibrating in this manner the highest stresses would occur near the hub and failures at this point could be explained. This question will have to be investigated thoroughly as it has an important bearing on the propeller problem. It is also possible that no resonance is present, as it can be shown that a forced motion in the plane of maximum stiffness could lead to very high stresses. This forced movement could result from torsional resonance of the crankshaft or from transverse motion of the entire engine and propeller in space. (See Figs. 14, 15, 16, and 17.)

As the theoretical considerations were rather involved, simultaneous researches were started to permit measuring the engine motion for six degrees of freedom and to measure and analyze the actual vibrating stresses in the propeller blades. While photo-elastic methods are to be interpreted with some caution, they are of some interest in the study of notch effects; the example shown in Fig. 18 was taken in connection with the study of a propeller blade which failed at the root of the retaining fillet when the vibratory stress in the shank showed a value of about 3500 lbs. per sq.in. The photo-elastic study indicates a stress concentration factor of about 4 which is in some agreement with fatigue strength of the aluminum alloy material of about 14,000 lbs. per sq.in. Chafing of the surface could account for failure at a comparatively small number of reversals.

The aerodynamic trends are sufficiently well understood so that we know certain desirable modifications which we should like to make in the propeller designs. For example, we know that the use of thinner airfoils would permit higher tip speeds without serious efficiency loss. There are also certain modifications in the planform which would lead to higher aerodynamic efficiency.

We are limited in making such improvements by the structural strength of the propellers and this strength is usually determined by the conditions of repeated stress resulting from vibratory loads rather than by considerations of steady stress. For this reason the chief concern of the propeller designer at the moment is with limitations imposed by vibratory stresses and a study of this problem appears to offer the greatest field

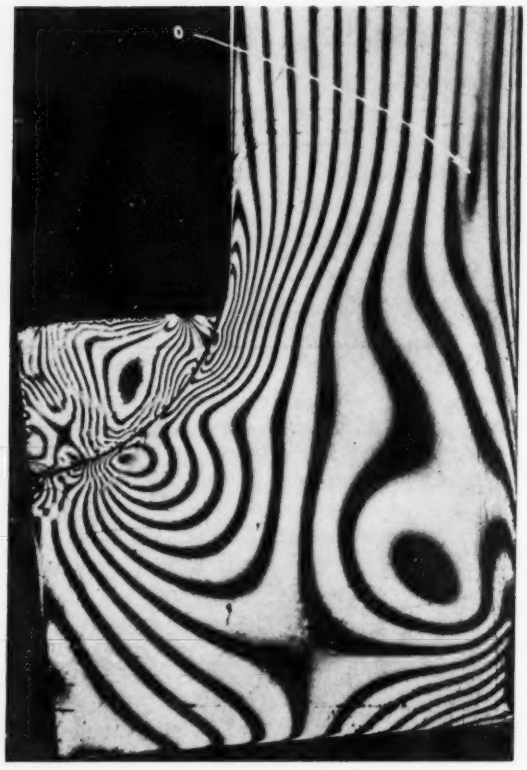


FIG. 18. Photoelastic analysis of stress distribution in the shank of a controllable pitch propeller blade.

for the improvement of the propeller safety and, indirectly, for the improvement of efficiency by removing some of the limitations on the aerodynamic design.

The whole propeller vibration problem is quite complex due to the large number of sources of excitation. Some of the more frequent sources of excitation are: the explosions of the engine; the secondary unbalance of the engine; breathing of the crankcase; inequality of torque due to the articulated master rod construction; unequal distribution of the combustion charge due to a variety of causes; torsional resonance of the crankshaft of the engine; tuning fork vibration of the crankthrow; resonance effects from the relation of the mass and inertia of the engine to the spring characteristics of the mounting structure; aerodynamic excitation due to obstacles in the slipstream; aerodynamic excitation due to the rhythmic flow of the vortices. Fortunately, there are a number of possible damping factors such as: internal damping or hysteresis of the material; frictional damping due to joints or connections of the propeller structure; impact damping; tuned spring type damping effective only at one frequency; pendulum type of damping effective only at a fixed number of cycles for each revolution; damping due to aerodynamic forces. The frictional damping and aerodynamic damping are always present and are of great importance to the propeller design.

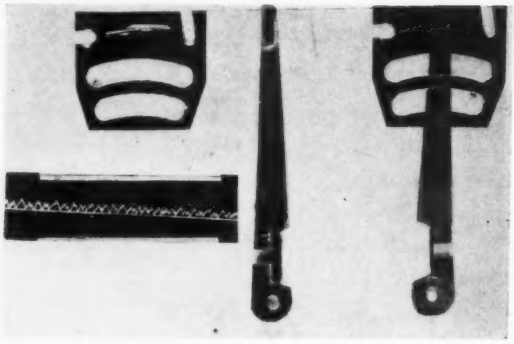


FIG. 19. DeForest scratch type extensometer. (Photo and record.)

METHODS OF MEASURING STRESS

The problem of measuring the vibratory stresses of the running propeller has been approached in a number of different ways. The greatest amount of effort has been applied to the use of strain gages and, among these, the types using electrical pick-ups appear to be the most adaptable. The electromagnetic strain gage has been used as a pick-up but this type tends to become bulky, requires rather fine wires, and is necessarily somewhat fragile in construction. It has the further disadvantage of depending on velocity and requiring an integrating electrical circuit for the indications.

The scheme of inertia magnetic-type pick-up also has been tried, but this method has the same disadvantages as the electromagnetic strain gage with the further disadvantage of being less positive in its action.

Some very good results have been obtained with the use of Piezo electric crystals, such as Rochelle salts, used as a pick-up for the vibration stresses. This type of pick-up measures curvature rather than stress, does not have a straight-line calibration of output against stress, and is affected by temperatures above 100°F. The crystals also are quite fragile. Various apparatus and methods for measuring stress are illustrated in Figs. 19, 20, and 21.

The most useful information so far has been obtained from electromagnetic pick-ups, for the motion of the engine and for the crankshaft vibrations, and from electrically strain sensitive resistance strips, for the propeller stresses. Some valuable results have also been obtained from the scratch type of extensometer, though the usefulness of this device is limited.

The best results obtained to date have been with a modified carbon-pile type of pick-up in which a flat bar of carbon is cemented to the surface of the blade with a suitable insulator and the change in resistance, due to variation in stress, is measured by a suitable electrical circuit. By using the proper binder for the carbon a very stable type of pick-up not affected by ordinary variations in moisture and temperature has been obtained. The output is rather high so that

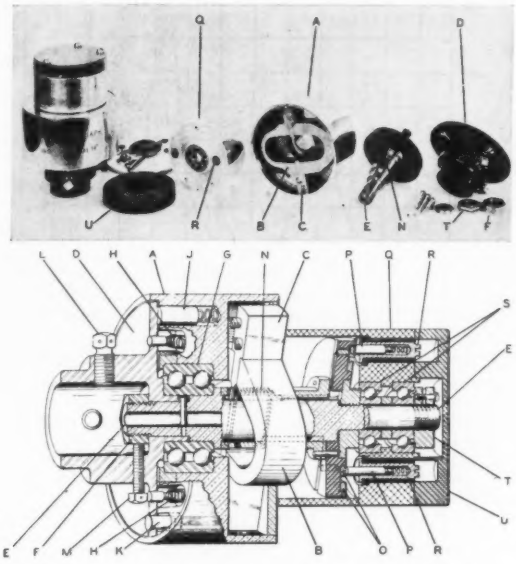


FIG. 20. Torsional pick-up. (Photo and section.)

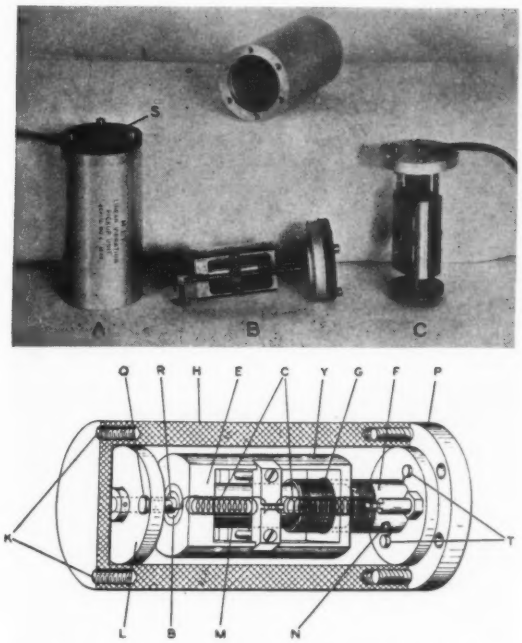


FIG. 21. Linear pick-up. (Photo and section.)

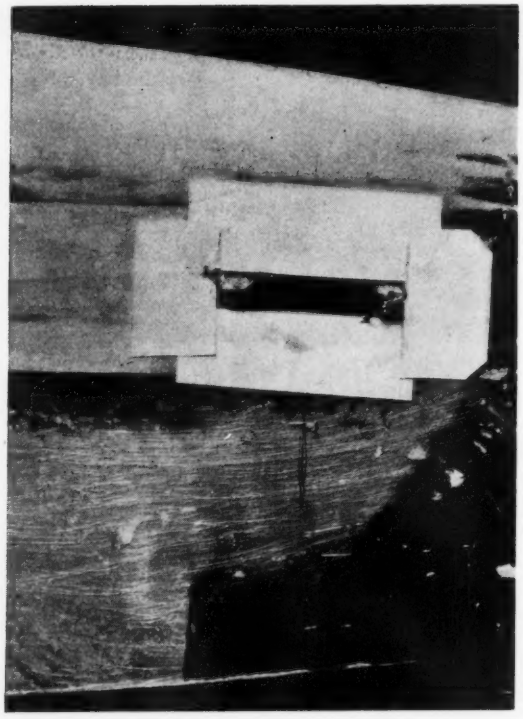
stresses of a low order may be measured. The output also is proportional to the stress so that the problem of calibration is simplified. It has been found possible to calibrate the pick-ups under static loading, this calibration being checked and found unchanged under dynamic loading.

While descriptions of this apparatus have previously been published, it may be worth while to illustrate an example of a typical curve of crankshaft vibration with the corresponding propellers stress and a typical set of curves showing the motion in space, together with the corresponding propeller stresses. In practice, the resistance extensometer is attached to a propeller blade by means of commercial DeKhotinsky cement. This cement which melts at approximately 300°F., is satisfactory only in the "hard" grade. To attach a strain gage, the blade is heated by a blow-torch until the cement flows freely. An insulating sheet of ordinary paper is laid on the cement and another layer of cement applied to the surface of the paper. The strain gage is laid in this cement with the long axis of the gage in the direction in which the strain is to be measured and held firmly in this position until the cement has hardened. The entire operation of applying a strain gage must be quickly accomplished as stated; the blade must be cooled and cleaned with alcohol before starting again. A good bond is easy to obtain if the blade is heated sufficiently and the stick of cement touched occasionally to the metal to test the temperature at a point near the pick-up position.

The lead wires from the shank of the blade to the strain gage consist of approximately #30 cotton-covered wire and these are cemented to a strip of paper insulation cemented in turn to the propeller blade with "Vulcalock" rubber cement. To protect the wires a second layer of paper is cemented over them and the cement allowed to dry for not less than five or six hours before testing on the engine. For vibration strain measurement the resistance extensometer is placed in series with a fixed resistance equal to the resistance of the unstrained extensometer and connected across a source of d.c. voltage. The usual value of the latter is from 45 to 90 volts. Since the resistance of the extensometer is a linear function of the strain the voltage drop across the matching resistance, as a function of the current in the circuit, will also be a linear function of the strain. This varying voltage drop is impressed across the input terminals of a high-frequency amplifier and the output measured with an oscillograph. In practice the output wave is photographed and by means of the overall calibration of the amplifier and oscillograph the input voltage to the amplifier is obtained.

The essential features of the pick-up circuit are shown in Fig. 22. Steady stress or the mean of the vibratory stress may be obtained by measuring the mean resistance of the strain gage by the use of a Wheatstone's bridge.

In general, the problem of slip rings is not very serious if the extensometer has a resistance of 20,000 ohms. The current carried by the rings is very minute and the variable contact resistance of the rings does not impair the quality of the wave from the extensometer. The material found most satisfactory for brushes is a mixture of copper and graphite used in plating generator brushes. The calibration is obtained statically. The strain gage is mounted on a sample



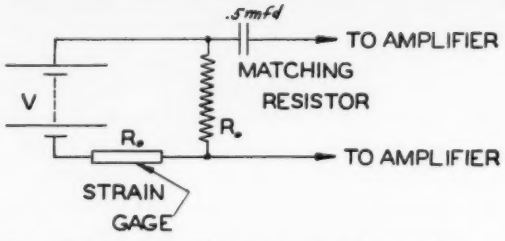


FIG. 22. Hamilton Standard electrically sensitive resistance strain gage. (Photo and circuit.)

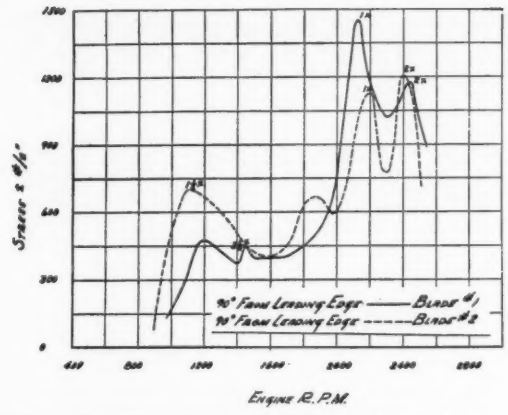


FIG. 23. Shank stress of propeller blade. (Measurements taken at 90° from leading edge.)

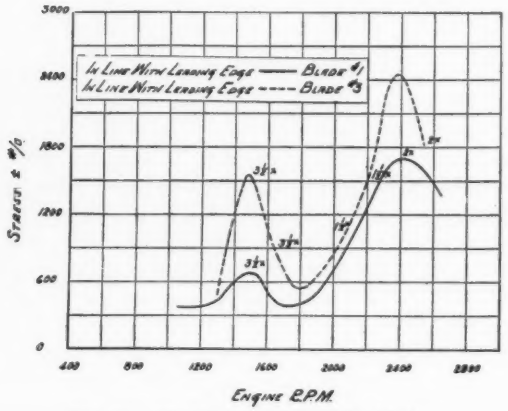


FIG. 24. Shank stress of propeller blades.

beam which can be loaded easily. A Huggenberger gage is mounted beside the resistance strain gage and the calibration made by checking resistance change *vs.* Huggenberger reading. An accurate measurement of resistance is made with a Wheatstone's bridge circuit. Quite a number of flight and engine tests already have been run with this setup, and a great deal of valuable information has been obtained. (See Figs. 23, 24, 25, and 27.)

While the most serious type of failures of propeller blades are those where fracture occurs near the hub, there are also certain cases where failure may occur near the tip of the blade. These failures are usually accelerated by nicks in the blades caused by striking small stones at the time of take-off. However, considerable vibration must be present in order to cause the repeated stress which leads to failure of the metal in fatigue. Fortunately, we have not yet had any failure of a Hamilton Standard controllable pitch propeller where fracture occurred near the shank end. We have, however, had a number of cases where a small piece has broken near the tip of the blade and failures of this type seem to occur at the rate of about one for each 50,000,000 propeller miles of flying. We have been making an intensive effort to determine the cause of these infrequent failures and have made some progress although the matter is not entirely clear. There seems to be some evidence of resonance in the case of the design in which these failures have been most frequent.

An example of the vibratory stress measurements taken near the tip of this blade shows a fairly consistent occurrence of a peak in the stress curve when the engine speed reaches 1680 r.p.m. The frequency of the stress alterations at this speed is equal to nine times the rate of revolution of the engine. Since the engine was a nine-cylinder type, the stress alternations were occurring at twice the explosion frequency. The measurements of vibration frequencies of this blade (Fig. 12) indicate that the third mode of symmetrical vibration should be in resonance at nine times engine speed at this rate of engine revolutions. In Fig. 26, for the purpose of illustration, the results of a number of different tests are shown on the same sheet. Some of these tests were taken when the engine was running on the test stand

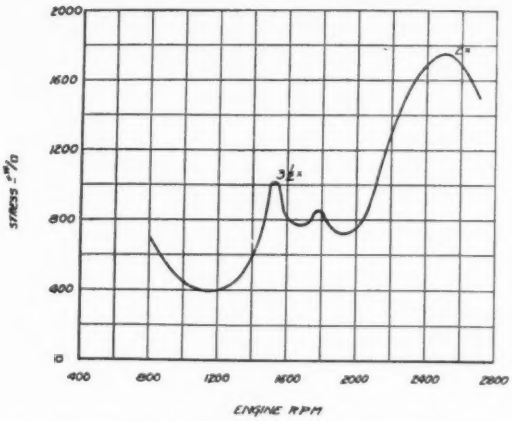


FIG. 25. Shank stress of propeller blades. (Measurements taken about 2 in. from hub in line with leading edge of section at 42 in. radius, using electrically strain sensitive carbon strip pick-ups.) (Blade 2.)

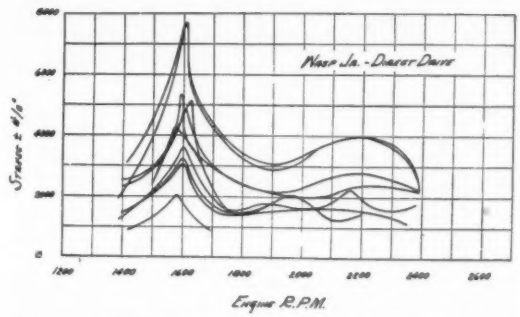


FIG. 26. Vibratory stress in propeller (Wasp Jr.—direct drive, 6905–6 blades) measured at a point 8, 10, and 12 in. from the tip at various engine speeds. Note resonance peak at 1600 r.p.m. at a frequency of 9 times engine speed as indicated by Fig. 12.

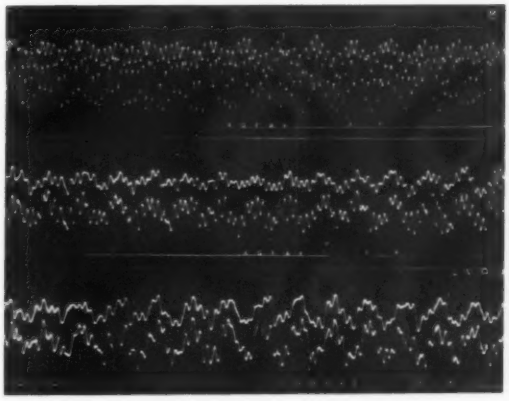


FIG. 27. Typical stress readings near the tip of a propeller blade taken in flight with the resistance type extensometer.

and others were taken in flight. The most interesting point about the curves is the fact that all of the tests show a sharp increase in stress at 1600 r.p.m.

One of the tests was made with an engine in which a dynamic damper had been fitted to operate at four and one-half times engine frequency to balance out the effect of the firing impulses of the engine. It is interesting to note that the damper actually raised the propeller stress in this case because the frequency of this stress was at nine times engine speed and the damper characteristics were such that a harmonic at nine times engine speed was present. Considerable difficulty has been experienced in trying to relate the frequency of these stress alternations to the natural frequency of the nonrotating propeller when excited at rest. The effect of the centrifugal force in changing the degree of fixity of the blade ends in the hub structure undoubtedly has an influence and experiments are being made to simulate this effect for the static tests.

Most of the stress readings up to the present time have been confined to taking two readings simultaneously on account of the problem of providing proper slip rings to conduct the current. We are now studying a plan to record simultaneously the motion of the engine along and about the three axes, the crankshaft torsion and the stress in the propeller blades at four locations. Simultaneous readings have the advantage of making it possible to observe the phase relation of the stress at different points and to draw some conclusions about the mode of vibration and the source of the excitation.

In addition to the electrical pick-ups, a good deal of work has been done with the scratch type of extensometer and some fairly successful records have been obtained. The work with mirror types employing a beam of light has only been partially successful.

Some information has been obtained from stroboscopic observations employing various types of stroboscopic lights such as the stroborama, stroboglow, and so on. However, it has been very difficult to get clear observations of the vibrations of the running propeller with the stroboscopic light, and the information obtained in this way has been very limited.

Some unusually interesting results have been obtained at the Massachusetts Institute of Technology by the use of high speed photography.

All of the various methods of testing stress measurement represent a useful effort, and it is likely that we shall have to continue to combine several kinds of tests in order to check the suitability of propellers from the standpoint of vibration stress.

DAMPING

The aerodynamic damping effects may be calculated for the flexural modes of vibration by applying the strip method and calculating the forces from the corresponding characteristics of the airfoil sections. It is necessary to assume a tip amplitude and, naturally, the deflection line of the vibrating propeller must be known. This may be obtained by experiment or by calculation.

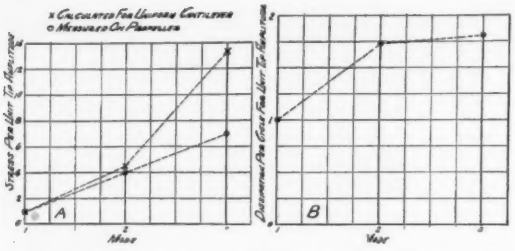


FIG. 28a. Typical stress distribution for various modes of vibration, and effect of aerodynamic damping. Ordinates represent maximum stress per unit tip amplitude for the second and third mode of vibration divided by the same quantity for the first mode. Two curves are shown, one as measured for an actual propeller, the other as calculated for a uniform cantilever beam.

FIG. 28b. Typical stress distribution for various modes of vibration, and effect of aerodynamic damping. Ordinates represent work lost per cycle of vibration in aerodynamic damping in the various modes divided by the work lost in the first mode, all for the same amplitude of vibration at the tips.

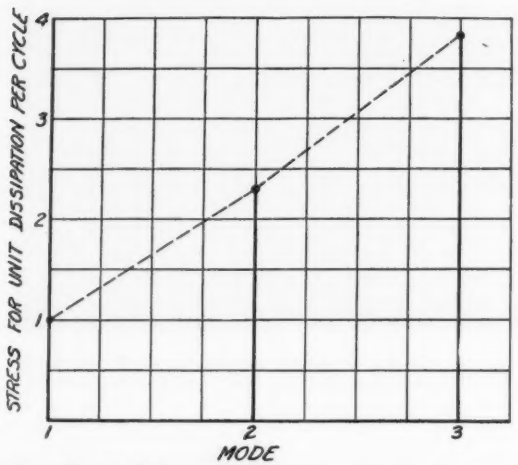


FIG. 29. Typical variation in stress per unit aerodynamic dissipation with mode of vibration. Ordinates represent stress in blade for the various modes of vibration for equal amounts of work lost per cycle, divided by the work lost in the first mode. The tip amplitudes for the higher modes are smaller than those in the lower modes. The diagram is found by the division of the stress per unit amplitude divided by the dissipation per cycle for unit tip amplitude.

It is of interest to compare the amount of damping present with the corresponding stress in the propeller blades. The calculations indicate that the damping for a given amplitude does not vary greatly for the fundamental and the first and second overtones. On the other hand, the stress is enormously higher for the higher overtones so that the aerodynamic damping tends to become less effective for the higher frequencies. (See Figs. 28 and 29.)

The aerodynamic effects are unstable in the case of torsional vibration of the blade and the damping may be negative in some cases unless the torsion is coupled with flexural vibrations in which case the damping problem becomes very complex.

The effect of frictional damping in the hub attachment is a difficult one to appraise in a quantitative

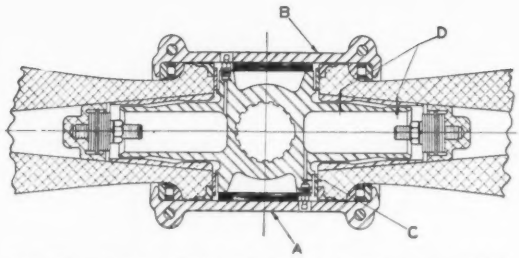


FIG. 30. Due to stretch of the hub barrel "A-B" which amounts to about 0.018 in. under the action of the centrifugal force, there is a normal clearance at "C" between the blade end and the spider abutment. There is also a very small clearance at "D" between the spider arms and the blade bushing.

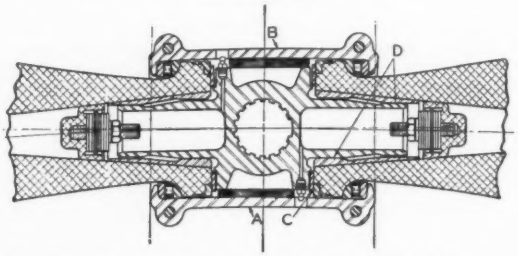


FIG. 31. For moderate deflections under vibration, the spring in the barrel permits one side, such as "B," to elongate more than "A," and the spider arm is bent resulting in frictional damping at "D." If the motion becomes extreme, the clearance of "C" is taken up and the impact at "C" tends further to damp the motion.

manner. In the case of the design shown in the figures there is considerable frictional work done as evidenced by the chafing of the metal surfaces between the blade bushings and the spider arms which mate with them. Since these particular parts are not very highly stressed at the points where the chafing occurs, this is probably a good place to absorb the damping energy. (See Figs. 30 and 31.) Frictional damping is probably more effective in reducing the harmful effects of forced vibrations than in insulating the type of excitation which might cause resonance vibrations. The coefficient of static friction is usually higher than the coefficient for sliding so that impulses of a certain magnitude can be transmitted before sliding takes place. Since only a small amount of energy is needed for high stresses in resonance vibrations, the frictional damping may not be effective in these cases.

In concluding this paper, I think that I should offer an explanation as to why so much space has been devoted to the subject of vibration. Since the propeller is one of the major structural elements of the airplane, and is only second to the wing and body structure as to importance, from the safety viewpoint, we have to design for a complete freedom from structural failure. Our past effort in this direction has been limited by the extent to which we have been able to avoid fatigue failures introduced by vibratory stresses. It, therefore, appears to us that our progress with the large propellers is going to be limited by what we are able to do about the vibration problem.

Wind Structure in Winter Storms

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SUMMARY

Observations, taken during two winter storms with a group of sensitive anemometers, are presented and analyzed. Vertical sections of passing gusts for a height of 250 ft. and horizontal sections across a width of 660 ft. were obtained. Iso-velocity contours were drawn to show the structure of passing gusts. Contours were also drawn for theoretical cases of flow, from which it was possible to identify several aspects of vortical motion in the atmosphere.

INFORMATION of a new type regarding the structure of the wind has been obtained at the University of Michigan during the past several years. The investigations were undertaken in 1927 as part of a general research into the strength and the wind loading of electric power lines under storm conditions.[1] The study was financed in the beginning by the National Electric Light Association, but since 1932 has been continued as independent research by the authors, with assistance from University research funds, the National Youth Administration, and the Airship Committee of the U. S. Navy.[2]

The material presented in this article was derived from two winter storms of considerable intensity. One of them, that of April 28, 1931, was analyzed only to the extent of showing wind structure diagrams for two gusts. The other storm, that of January 19, 1933, was more completely analyzed so as to include several wind structure diagrams; a study of the variation of wind velocity with height and the correlation with the gradient velocity; and a statistical study of gustiness.

INSTRUMENTS AND METHODS

The site of the experimental station is near Ann Arbor, Michigan, on a ridge of land whose axis is approximately normal to the prevailing storm winds. The windward side of the ridge has a gentle slope of about 175 ft. in 4 miles, and contains occasional farm buildings and groups of trees. The nearest obstruction is a grove at a distance of about $^3/_8$ of a mile, and at such an elevation that the tops of the trees are level with the top of the ridge.

A steel tower 250 ft. high was used with anemometers at 25 and 50 ft. intervals. Anemometers were also mounted on 12 poles 50 ft. high, spaced 60 ft. apart. From this arrangement it was possible to obtain a horizontal section of a passing gust at a height of 50 ft. above the ground and over a front of 660 ft. When some of the anemometers were placed on the tower instead of on the wood poles, it was possible to obtain simultaneously a horizontal and a vertical section of the passing gusts.

FIG. 1. Pressure plate anemometer installed on a tower station.

New Type Anemometers

A study of the records of commercially available anemometers led to the conclusion that, because of the inertia of the moving parts of the instruments, the records could be accepted as accurate only if they were averaged over an interval of 10 seconds or more. This degree of responsiveness was not sufficient to disclose the characteristics of the passing gusts. An anemometer was therefore developed which would record accurately the average velocity for intervals of time as short as $^1/_4$ second or even shorter.

The new type of instrument has a pressure plate 9 in. high and 8 in. wide hinged near the bottom. Pressure against the plate is carried by a rod to a magnetic transmitter. The wind pressure changes the air gap of the transmitter, thus controlling the amount of current passing through its coil. The current was recorded by a 12-element oscillograph, which permitted the taking of simultaneous records from twelve anemometers.

The pressure plate has a maximum movement of about 0.005 in., and a natural frequency of vibration of about 115 cycles per second. About 0.12 second is required for the instrument to complete its response to a change of velocity from 80 m.p.h. to zero. The extreme error due to temperature effects is 0.27 m.p.h.; that due

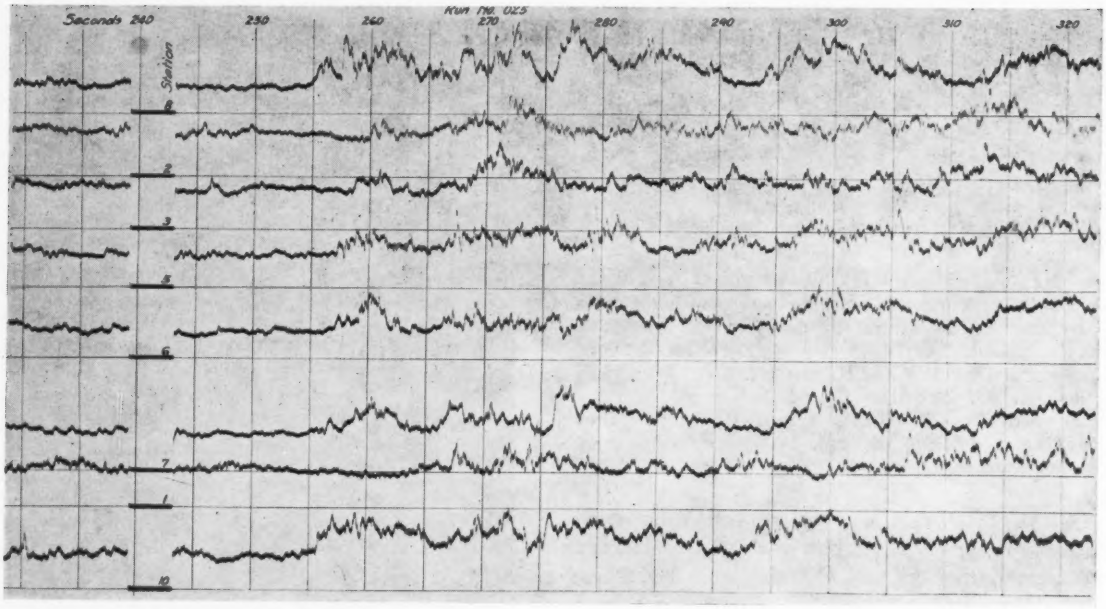


FIG. 2. Original chart, part of run 025.

to imperfect leveling, 0.45 m.p.h.; and momentary errors due to the lag of the anemometer in responding to changes of wind direction, 1.25 m.p.h. A complete description of the anemometer and its recording instrument has already been published[3] as well as a preliminary description of the method of drawing and interpreting wind structure diagrams.[4] A photograph of one of the anemometers mounted on a tower station is shown in Fig. 1.

Method of Taking Records

The records from the 12-element oscillograph were made directly on sensitized paper which was obtained in rolls 12 in. wide and 100 ft. long. A chart speed of either 6 in. or 12 in. per minute was used, depending upon the intensity of the storm and the manner in which it was expected the records would be used. A typical record is shown in Fig. 2.

Transparent templates, inscribed with finely divided grids, were used to obtain data from the original charts. The zero-line of the grid was made to coincide with the electrical zero-line of the record and values of deflection were read through a magnifying glass. These values were entered in tabular forms and later converted to velocities through the calibration established for each combination of an anemometer with an oscillograph element.

The records of every storm were divided into runs of from 6 to 12 minutes each, with an interval of about one minute between runs. This article discusses wind gusts which occurred near the middle of Run 330 on the afternoon of April 28, 1931, and during Runs 025 and 026 in the storm of January 19, 1933.

Diagrams of Wind Structure

One of the most important objectives of this work was to obtain additional knowledge of the structure of wind gusts. For the purpose of showing the structure graphically, diagrams were prepared from the records in such a way that the character of the turbulence would be disclosed by inspection, as in Figs. 3 and 4. The data for these two diagrms are taken from Run 330, during the storm of April 28, 1931. Fig. 3 shows the variations that occurred in both a horizontal and a vertical section during an interval of 22 seconds. Spacing of the anemometers was used as ordinates, and time as abscissas. Time was divided into intervals of $^1/_2$ second and the average wind velocity in m.p.h. was recorded for each interval at each anemometer. Contour lines were drawn so that any given line represents a particular velocity and passes through only those periods in which that particular velocity was recorded by the anemometers. These lines, referred to as iso-velocity contours, indicate by their spacing the rapidity with which the velocity is changing.

A well-defined gust front appeared at Station 6 during the last half of Second 344 and spread to all the horizontal stations within the next 6 seconds. After the front had passed, the gust maintained a high average velocity at all stations with, however, rather rapid accelerations appearing in some places. It is interesting to note that the front of the gust reached the upper stations of the tower several seconds before it reached the 50 ft. level, and that a strikingly symmetrical eddy occurred near the top of the tower immediately following the front of the gust. These conditions are very similar

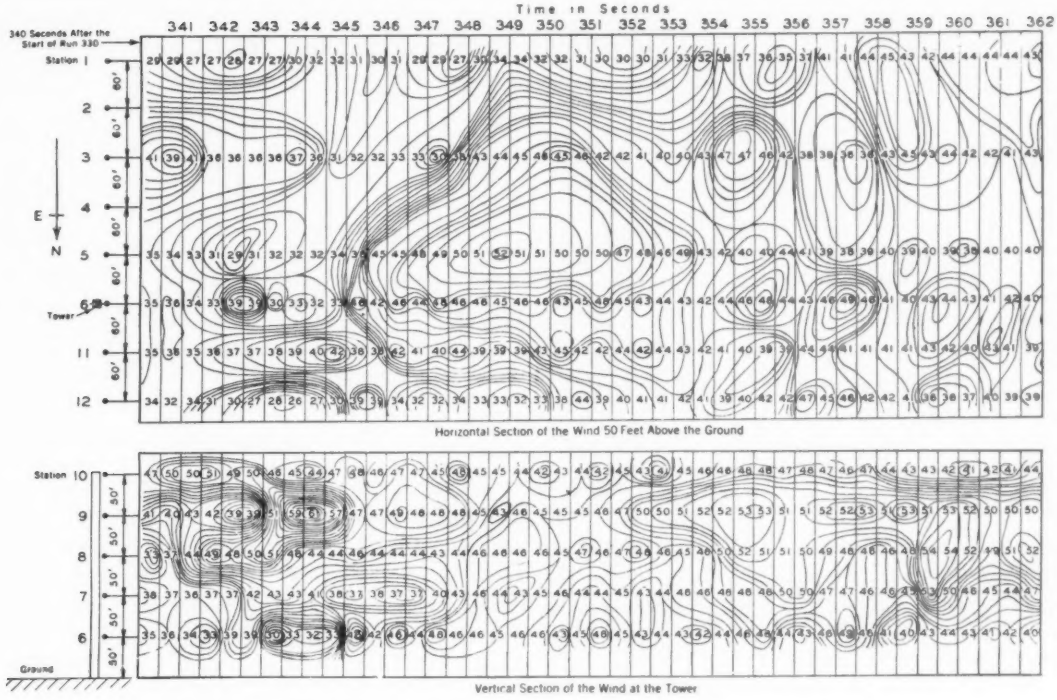

Time in Seconds
340 Seconds After the Start of Run 330
Station 1
Tower
Horizontal Section of the Wind 50 Feet Above the Ground
Station 10
Ground
Vertical Section of the Wind at the Tower

FIG. 3. Wind gust shown by iso-velocity contours, run 330. (Secs. 340–362.)

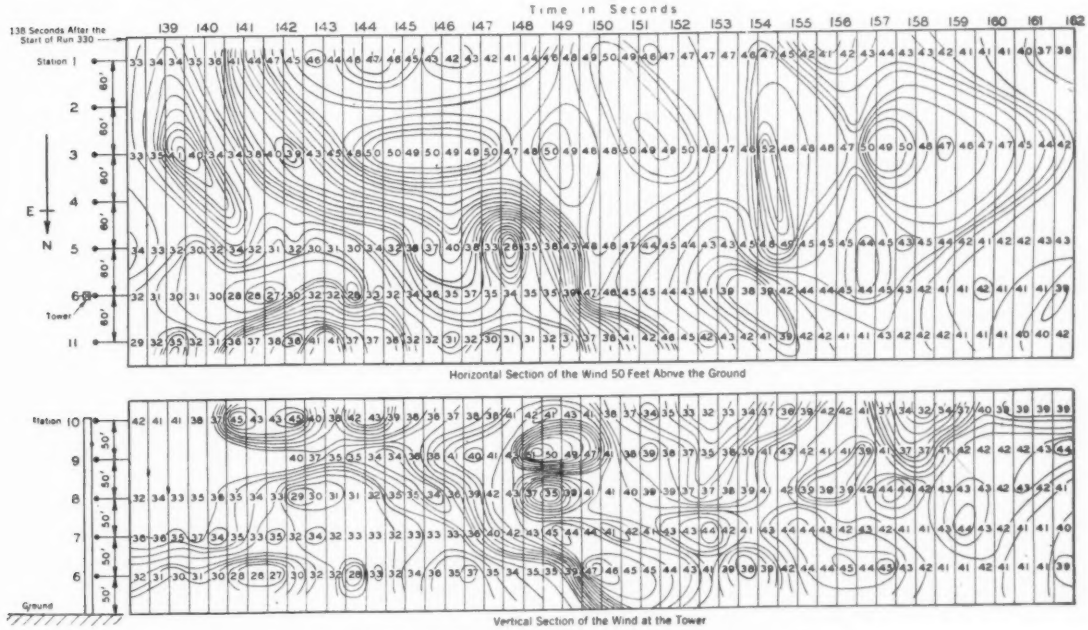

Time in Seconds
138 Seconds After the Start of Run 330
Station 1
Tower
Horizontal Section of the Wind 50 Feet Above the Ground
Station 10
Ground
Vertical Section of the Wind at the Tower

FIG. 4. Wind gust shown by iso-velocity contours, run 330. (Secs. 138–162.)

to those which existed at the beginning of an earlier gust, as shown in Fig. 4, except for the relative positions of the zones of high and low velocity. This combination of zones of high and low velocity occurs frequently throughout all the diagrams, particularly in the region immediately following the passage of the gust front. The relative position of the high and low velocity zones in the configurations varies considerably, but there is a similarity which suggests that they represent different aspects of a common type of flow.

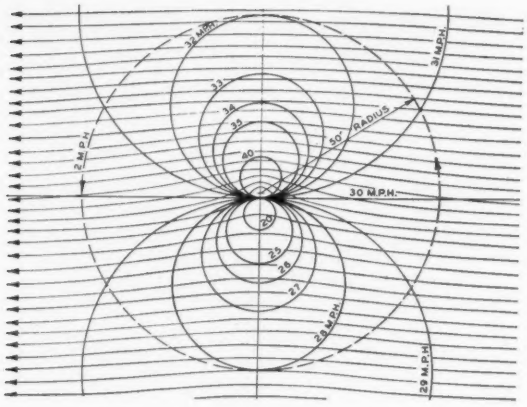


FIG. 5. Vortex superimposed on uniform flow.

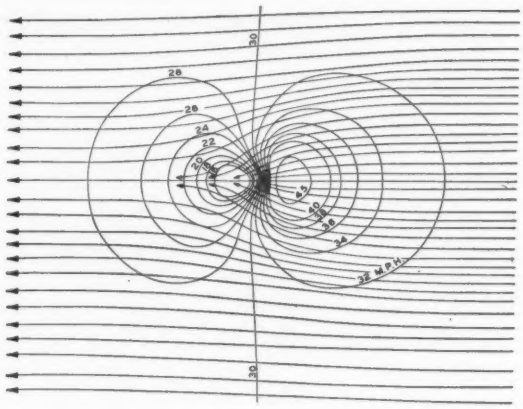


FIG. 6. Sink superimposed on uniform flow.

Theoretical Types of Eddies

Iso-velocity contours for several theoretical cases have been constructed for the purpose of identifying the types of flow disclosed by the regular configurations in the wind diagrams. Several such cases will now be discussed.

In Fig. 5 are shown the stream lines and iso-velocity contours near a vortex whose center is traveling at the rate of 30 m.p.h. The strength of the vortex is such that at a distance of 50 ft. from its center the tangential velocity is 2 m.p.h. The resultant velocity at any point is obtained by taking the vector sum of the two component velocities. There is a zone of high velocity in the upper half of the diagram and a zone of low velocity in the lower half, with a steep velocity gradient between them. Since one of the characteristics of a vortex is that the tangential velocities increase toward the center inversely as the radius, there is, theoretically, a point at which the tangential velocity is just equal to the velocity of translation, giving, in this case, a point of zero velocity a short distance below the vortex center. Between this point and the vortex center the resultant velocity is in the direction opposite to the velocity of translation.

As the velocity increases toward the center of the vortex there is a decrease in the static pressure, and consequently a necessity for air to rush into the open ends of the vortex cylinder and to form sinks. This involves a tendency for the vortex to disintegrate through the equalization of the pressure differences necessary to maintain it. In the natural air there is sufficient viscosity to slow down the disintegrating process and to permit the vortex to maintain itself by losing at its circumferential boundary an amount of air equal to that which flows into the ends of the cylinder.

Stream lines and iso-velocity contours for the theoretical case of an aerodynamic sink traveling at the rate of 30 m.p.h. are shown in Fig. 6. The velocity of translation is parallel to the plane of reference and the velocities in the sink converge from all directions to the center, which is 10 ft. away from the plane of reference. The strength of the sink is such that about 92,000 cu.ft. of air per second disappear at its center from all directions. The stream lines and iso-velocity contours were obtained by taking the components of the velocities in the sink as they pass the plane of reference, and combining them vectorially with the velocity of translation in the plane.

Each of these two theoretical cases has a zone of high velocity and a zone of low velocity. In the case of the vortex, the two zones are side by side in the stream, but in the case of the sink the high zone follows the low zone. In both cases there is a steep velocity gradient between the two zones. In the case of the sink, the high zone tends to envelop the low zone, the amount of this enveloping tendency depending upon the relative strengths of the sink and of the uniform flow.

Two additional theoretical cases are pictured in Figs. 7 and 8. The combinations have been suggested by configurations of the iso-velocity contours appearing frequently in the wind structure diagrams. Fig. 7 is a combination of a vortex, having a counterclockwise sense of rotation, with a sink and uniform flow. Fig. 8 is a combination of a vortex, having a clockwise sense of rotation, with a source and uniform flow. In each case the vortex has the same strength as the one shown in Fig. 5, namely, 2 m.p.h. at a distance of 50 ft. from the center; the source and the sink each has the same strength as the sink in Fig. 6, namely, 92,000 cu.ft. of air per second, and in each case the velocity of translation is 30 m.p.h.

It will be seen that the chief difference between the configurations resulting from 3 components of flow and those resulting from 2 components is that the axes, joining the high- and low-velocity zones, occupy diagonal positions with respect to the direction of translation. In all cases the iso-velocity contour for 30 m.p.h., the velocity of translation, establishes the division between the high- and the low-velocity zones. This is important since it provides a means of identifying the velocity

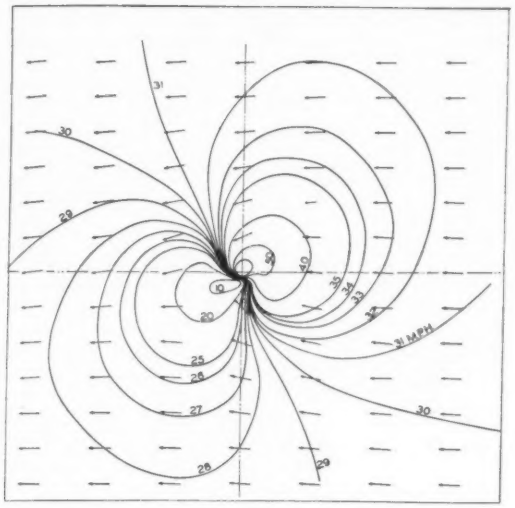


FIG. 7. Counter-clockwise vortex, sink and uniform flow.

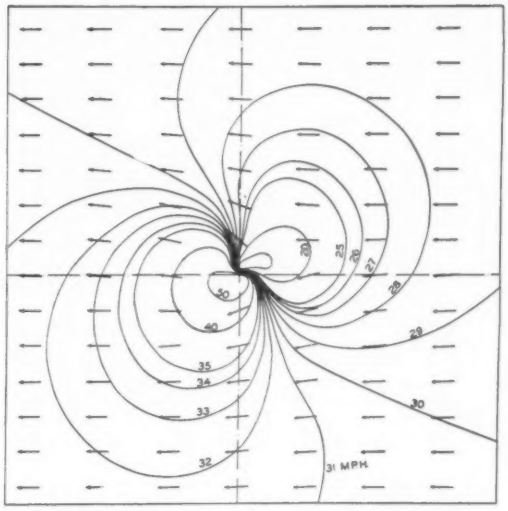


FIG. 8. Clockwise vortex, source and uniform flow.

of translation of the eddies appearing in the wind structure diagrams.

The arrows in these theoretical fields indicate the direction of flow. It is important to notice that large deviations from the direction of translation appear only near the center of the vortex or sink, or any combination of vortex, source, sink, or translation. In other words, even if the eddies in the atmosphere were visible to the eye, it would be possible to identify only a very small core of the eddies since, at all other points in the field, the direction of flow is substantially that of the direction of translation. Of course it would be possible to increase the size of the visible core in the diagram by increasing the strength of the vortex and decreasing the velocity of translation. However, the velocity of translation and the strength of the vortex, source, and sink were chosen so as to produce iso-velocity contours comparable to those disclosed by the records.

Eddies in the Atmosphere

The cases of the vortex and the sink are easily observed in water because the direction and velocity of flow are visible. In the case of water flowing into a vertical drain pipe, as in a kitchen sink, the characteristics of both a vortex and a sink are present. In the natural wind, however, these phenomena are not visible, except when the air is laden with snow or dust, at which times the core of the vortex is frequently outlined quite sharply, showing not only the tangential velocities of the vortex, but also the inflow or sink at its bottom boundary, and the outward flow, or source, higher up where disintegration is apparently taking place.

It is reasonable to expect that the theoretical cases will rarely be reproduced perfectly in the natural wind, since eddies in the wind stream are constantly undergoing changes from various causes. Furthermore, this method of measuring and recording the structure of wind gusts shows the shape of the eddies as they pass the line of anemometers and not as they exist in their entirety in any instant. If, therefore, an eddy starts to disintegrate or to combine with another eddy just as its boundary reaches the anemometers, the configuration of the iso-velocity contours in the upstream part of the eddy will be less perfect than in the downstream part. Moreover, a vortex may present many apsects besides the four theoretical cases treated here. Its flow may be two dimensional or three dimensional; its axis may be straight, curved, horizontal, vertical, or inclined.

Storm of April 28, 1931

By reference to Fig. 4, Secs. 147 to 150, it will be seen that the configuration of the iso-velocity lines at the upper stations of the tower indicates the presence of a vortex whose axis is approximately horizontal and whose direction or rotation is counterclockwise. There is a well-defined zone of high velocity and one of low velocity with a gradient amounting to 16 m.p.h. in a vertical distance of 50 ft. This vortex is generated chiefly by the difference in the velocities of the upper and lower strata, as the lower strata lagged behind the upper because of friction with the ground and the viscosity of the air.

A well-defined sink, which appeared at the upper stations of the tower during Secs. 341 to 345 is shown in Fig. 3. Here the zone of high velocity follows that of low velocity in the wind stream, and a very steep velocity gradient exists between the two zones. The tendency for the high zone to envelop the low zone is more pronounced here than in the theoretical case shown in Fig. 6.

There are several places in the horizontal sections of the gusts in Figs. 3 and 4 where the configurations are

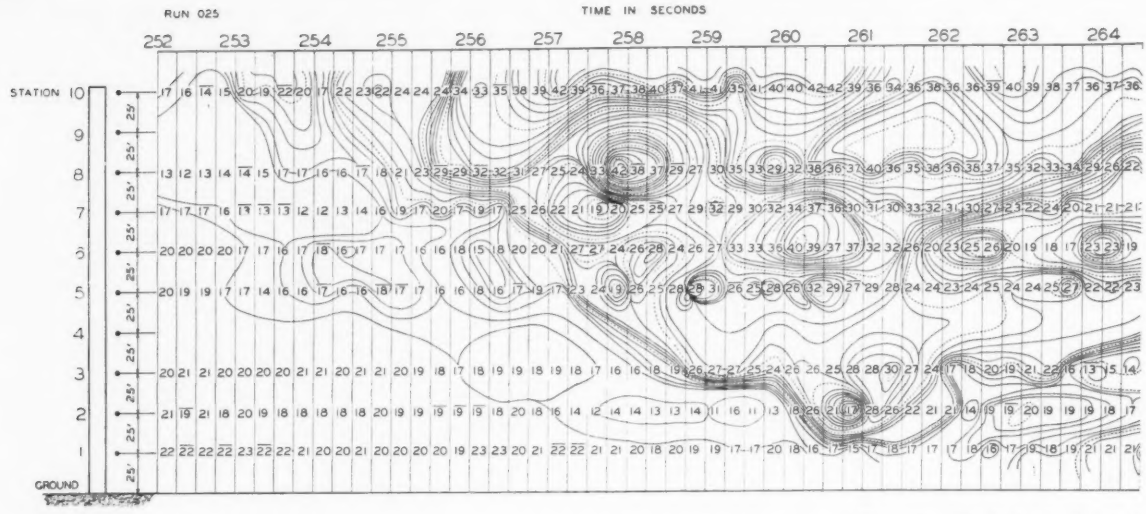


FIG. 9. Vertical section of

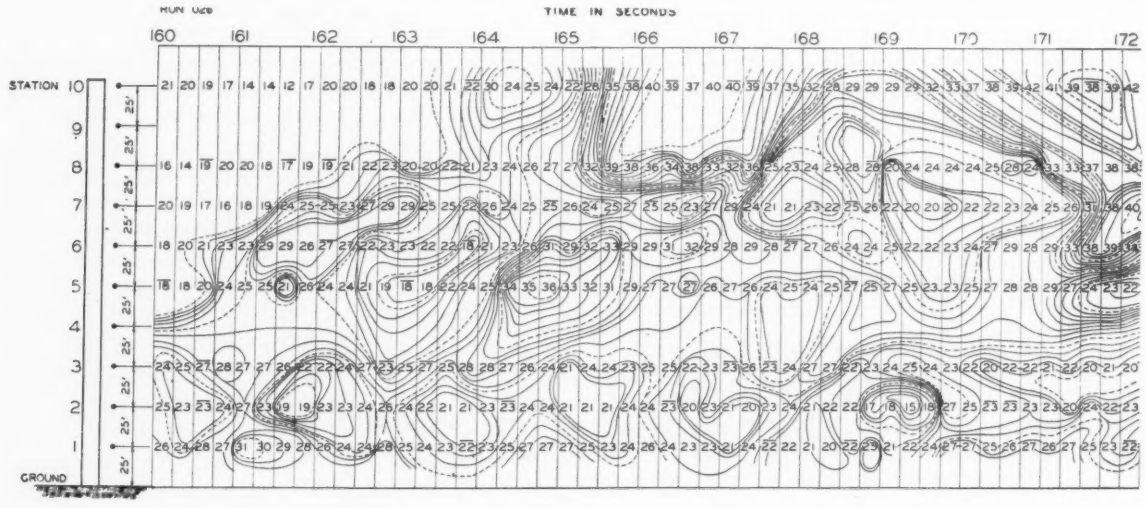


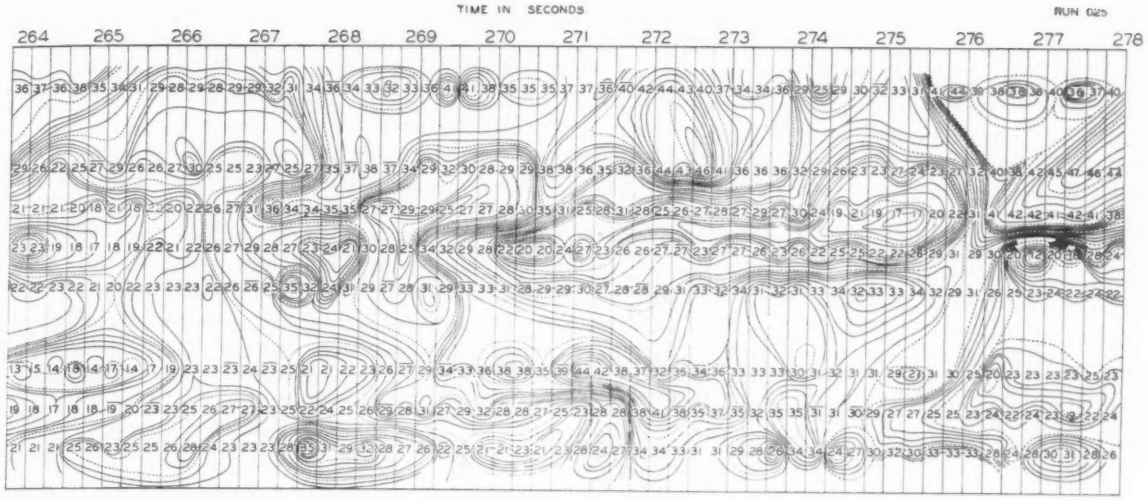
FIG. 10. Vertical section of

similar to the theoretical configuration of a vortex combined with a sink and uniform flow, as, for example, during Secs. 152 to 156 and 356 to 360. Such a combination of flow may very well exist in the case of a vortex whose axis is nearly vertical, and whose lower boundary is near the plane of reference. Under this condition the horizontal section near the bottom end of the vertical vortex cylinder would include the upward velocity components of the inflowing air as well as the tangential components of the vortex.

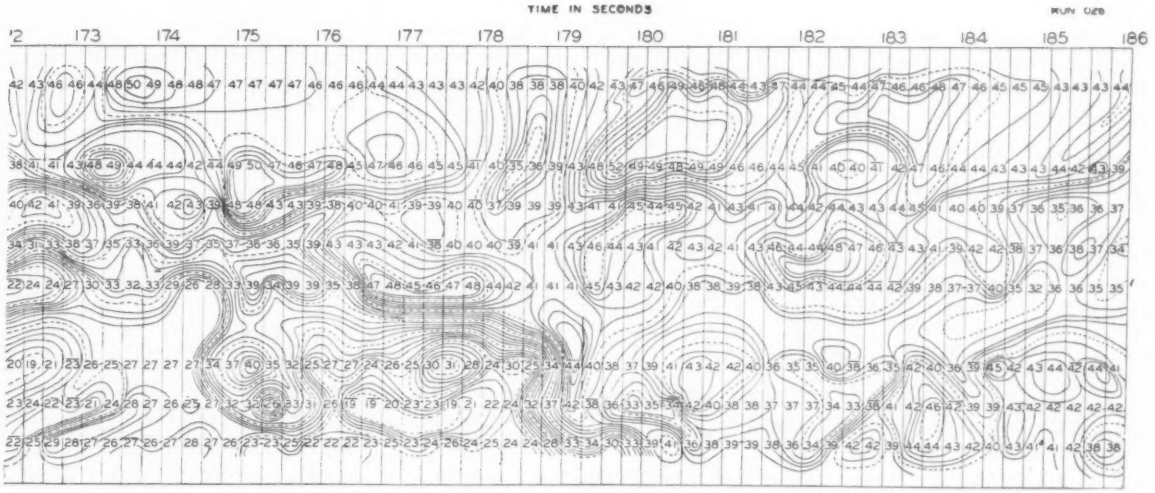
There is an upper and a lower limit to the size of the eddies which can be disclosed by any given combination of anemometer spacing and length of time interval. For example, the combination of 50 and 60 ft. spacing of the anemometers with time intervals of $1/2$ sec. is about the least refined combination which could have been used without losing all indication of the presence of the eddies which are here disclosed. If the spacing of the anemometers on the tower had been 100 ft. instead of 50 ft. the vortex during Secs. 147 to 150 would have appeared merely as an irregularity in the iso-velocity contours.

Storm of January 19, 1933

After the winter of 1930-31, the chart speed was increased in order that time intervals of $1/4$ sec. might be used on any records that involved high velocities. The eddies which are barely disclosed in the records in Figs. 3 and 4, with average velocities between 35 and 40 m.p.h., would be completely lost in records with higher average velocities, unless the length of time intervals were decreased as the velocity increases. Furthermore, the full benefit of decreasing the length of the time intervals would not be obtained without a corresponding



gust, run 025. (Secs. 252–278.)



gust, run 026. (Secs. 160–186.)

decrease in the spacing of the anemometers. Consequently, during the storm of January 19, 1933, the spacing of the anemometers on the tower was 25 ft., thus giving 10 stations instead of 5.

Figs. 9 and 10 are wind diagrams for the storm of January 19, 1933. It will be noticed that the numbering of the stations on the tower has been changed from that of the storm previously described; also, that the records of wind velocity are missing for the stations at the 100 and 225 ft. levels. Each number in the diagram represents the average velocity for a one-quarter second interval of time, instead of one-half second as previously used.

Fig. 9, Secs. 252 to 278, shows the front of a gust and a small part of the structure following the front. Preceding the gust there is a period of about 40 seconds during which the wind velocity was relatively low and free from turbulence. This is clearly shown on the original record in Fig. 2. The highest average velocity within this inactive period was at the lowest station, no doubt because of the upward deflection of the air by the sloping ground in front of the tower. The first onslaught of the gust did not reach the lowest station on the tower, but receded after about 10 seconds to a height above the 250 ft. level. After a short interval a second onslaught of the gust succeeded in pentrating to the lowest station. More than 12 seconds elapsed after the gust had reached the highest station before it was fully evident at the lowest.

Following the gust front, there is a well-defined combination of vortex and sink at Stations 7 and 8. The velocity of translation of this eddy was about 27 m.p.h., as shown by the iso-velocity contour separating the high-velocity zone from the low one. It is impractical to com-

pare the velocity of translation of a vortex with the average of the stream because of the difficulty of choosing a significant time interval over which to take the average of these turbulent velocities. The behavior of vortices seems to depend more upon rapid changes in velocity, and upon steep velocity gradients between stations, than upon anything which can be characterized by an average velocity.

Other configurations are present in the wake of the gust front, but they possess less regularity than the first one. For example, configurations indicating the presence of a vortex and sink are shown at Stations 5 and 6, Sec. 258, and a counterclockwise vortex in combination with a source during Secs. 267 and 268.

The presence of eddies can be detected in some cases on the original record, as in Fig. 2. As an example, the original record for Station 8, Secs. 257 and 258, shows quite distinctly the characteristic drop as the zone of low velocity passes the station, followed by a very steep velocity gradient as the front of the high velocity zone passes, and this in turn followed by the decreasing velocity as this latter zone recedes. The dip in the curve as the low velocity zone passes Station 7 is less jagged in appearance because the center of the vortex is not as close to it.

Fig. 10 shows a vertical section for Secs. 160 to 186, Run 026. Here again the front of the gust made several onslaughts before it succeeded in penetrating to the lowest station. The gust front has the appearance of irregular masses of air tumbling down from above. The velocities are, in general, higher than those shown in Fig. 9.

Discussion of Wind Diagrams

An inspection of the diagrams, and a comparison with the diagrams of theoretical cases, leaves no doubt that eddies of many different sizes exist in the turbulent atmosphere. The conditions which produce eddies and control their size have not yet been determined experimentally. The identification of these conditions awaits the more intensive study of existing records and the accumulation of additional records covering different size ranges. Indefinitely smaller eddies could be discovered by using closer spacing and smaller time intervals, but, as stated before, care must be used to preserve a proper relation between the spacing, time interval, wind velocity, and size of the space to be explored.

It is not certain whether the eddies are generated chiefly by steep gradients in the horizontal components of wind velocity or whether the vertical components also have an important influence. It is probable that the latter statement is correct because vertical components of velocity must exist as the front of the gust cuts its way downward toward the ground. However, the records on this investigation contain no information regarding vertical velocities since the pressure-plate anemometer rotates about its vertical axis only. It records the true resultant velocity only when the wind direction is horizontal. It is recognized that an error is introduced into the recorded horizontal component by any inclination of the resultant away from a normal to the pressure plate. The limiting magnitude of such errors has been determined experimentally for angularity in a horizontal plane, but not in a vertical plane.

In order for the surge to have reached the 50 ft. station within 5 seconds after it had reached the 200 ft. station, as shown at the front of the gust in Fig. 9, the effect must have traveled downward with a vertical velocity of about 30 ft. per sec., about 20 m.p.h. This effect could be produced through shear between horizontal layers, or through vertical displacement of masses of air having different velocities, or through a combination of these two means.

The phenomenon of vertical interchange due to thermal instability is well known. Violent gusts of thermodynamic origin, involving the vertical movement of large masses of air, occur during the passage of the areas of low barometric pressure. During the storms recorded in this investigation the highest velocities and the most violent gusts occurred within the southwest quadrant of low-pressure area, that is, while the cold front was passing, and during the time when the low-pressure area was receding and the high-pressure area was approaching. In this zone of transition there was a condition of thermal instability which permitted occasional and sometimes violent interchanges between the higher and lower strata. Large gusts near the ground occurred because masses of air from the more rapidly moving higher strata reached the ground before losing all of their excess forward momentum.

Experimental studies have been made by others to obtain quantitative information about the structure of the wind. All of these attempts have been limited in their scope and accuracy by the instruments available to the investigators. One of the most recent and most successful investigations of this kind was conducted by Wilhelm Schmidt.[5] By taking motion pictures of a line of pendulum plates and observing the angles through which they were deflected, he was able to determine the average wind velocities existing at the various plates for intervals of time as small as $^1/_7$ of a second, if the wind velocity did not exceed 10 meters per second (22.4 m.p.h.). The length and height of the front over which observations can be made in this way are rather limited. The purpose of his investigation was served by taking simultaneous records for a height of 1.5 meters and a width of 3 meters in one case, and for a height and width of 10 meters in another case.

For the purpose of showing graphically the structure of the wind Schmidt likewise used spacing of the anemometers as the ordinates and time as the abscissas. He indicated the zones of different velocity by different types of cross hatching. In his diagrams there were no indications of the presence of vortices. From the published results it is not clear whether this is due primarily to (1) the fact that his diagrams did not include gust fronts,

involving large differences in velocities; or (2) sluggishness of the pendulum plates; or (3) the fact that the time intervals over which his velocities were averaged were too large to disclose any eddies which could be encompassed in the relatively small dimensions of his apparatus. The last of these would seem to be sufficient explanation. The height of his time-space diagrams was 1.5 meters. When the velocity was 10 meters per second a vortex with a diameter of 1.5 meters would pass his pressure plates in a period of 0.15 seconds. At the rate of 7 readings per second only one reading would be obtained during the passage of a vortex. Even for velocities of translation as low as 3 meters per second, only about three readings would be obtained during the passage of the eddy, and these would scarcely be sufficient to identify it.

The arrangement and responsiveness of the anemometers on the investigation described in this article, permitted not only the mapping of wind structure, but also the identification of several aspects of vortical motion. It has been possible to identify a number of cases in which the regularity and shape of the iso-velocity contours approach that of the theoretical cases. The wind diagrams may also be used for purposes other than the identification of particular forms of air flow. The presentation of wind data in this form shows both the variation of velocity with time at a given place, and the variation in space at any instant of time. Wind pressure may be evaluated from the velocity data, yielding information as to the dynamic characteristics of gust forces, and the width or height affected by them. The original tabular collection of data, however, opens an even wider field of investigation which is still being explored, namely, the computation of correlation coefficients and other statistical quantities which may be used to search for orderly relationships in the apparently disordered atmosphere.

References

[1] Sherlock, R. H., and Stout, M. B., *Storm Loading and Strength of Wood Pole Lines*, Edison Electric Institute, 1936.

[2] A more detailed report has already been made to the Airship Committee, Prof. W. F. Durand, Chairman, and may be published later by the committee. The parts dealing with the variation of velocity with height and statistical analysis of turbulence have been omitted from this article, but they are being included in Engineering Research Bulletin No. 28, University of Michigan now being prepared for publication.

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Torsional Stability of Cylindrical Shells[1]

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Summary

THE design of thin-walled cylindrical shells carrying compressive loads can be greatly simplified by means of diagrams of "ellipse of critical stress." For a given form of cross-section and material, only one diagram is necessary. The average critical stress has an elliptical relation to certain dimensionless parameters of the geometry of the shell. Economical shells should have high torsional rigidity. Examples of the design of equal-legged angles and circular arc sections are here given, together with some of the experimental results.

Introduction

Aeronautical engineers have long been aware that thin-walled structural members carrying compressive loads fail before Euler's critical load has been reached. In practice this fact has been overcome by carrying out the design by means of empirical formulae (or "form factors") which in most cases were derived to suit the particular problem. Theoretical explanations were lacking.

S. Timoshenko[2] first pointed out that angles may fail due to twist, not necessarily due to Euler's buckling. He gave the equation for the critical load covering torsional stability of such angles. Rene Leduc[3] was the first to show that *any* member which lacks torsional rigidity will also be unable to resist pure compressive loads. The first satisfactory theory which covered a wide range of cylindrical shells was introduced by Wagner.[4,5]

This paper presents a very much abridged form of the original dissertation, in which a thorough analysis of Wagner's theory has been carried out. It was shown that the introduction of ellipses of critical stresses not only enables one to correlate Wagner's theory with that of other authors, but also shows how any particular stiffener can be designed most efficiently and economically.

Correction for the Torsional Bending Constant

It has been shown by H. Wagner[4] that the critical compressive load P_c on any open cylindrical shell can be expressed by

$$P_c = \frac{1}{i_s^2 + i_n e}\left(C + C_b E \frac{\pi^2}{L^2}\right) \qquad (1)$$

It can be recalled that, in the derivation, the torsional bending constant C_b is treated as a sum $C_b = C_{bs} + C_{bn}$ and it is claimed that C_b is a *geometrical* constant for a given cross-section. A rigorous analysis of Wagner's theory leads the author to a conclusion that for thin-walled shells the coefficient C_{bn} should always be taken with the factor $1/1 - \mu^2$ where μ is Poisson's ratio. Thus the corrected torsional-bending constant should read

$$C_b = C_{bs} + \frac{1}{1 - \mu^2} C_{bn} \qquad (2)$$

For most of the sections used in aeronautics this correction is not necessary because usually C_{bn} is very small compared with C_{bs} and can be neglected. In some cases, however, C_{bs} might be zero, then $C_b = (1/1 - \mu^2)C_{bn}$ must be used.

Ellipse of Critical Stress

For shells of constant wall thickness the form of the cross-section is determined by the shape and length S of its mid-line which in turn can be expressed by a function of a convenient linear parameter S'. For instance, equal-legged angles are fixed by the length of one leg, or circular arc sections can be identified by the radius of the arc and the central angle. In those cases the area A of the cross-section is equal to St. It can be shown from Eq. (1) that the average critical stress $\sigma_c = P_c/A$ will be

$$\sigma_c = \frac{1}{K_1^2 + K_2 f}\left(\frac{1}{3} G \frac{t^2}{S^2} + E\pi^2 B_s \frac{S^2}{L^2}\right) \qquad (3a)$$

for the cases when C_{bn} is small as compared with C_{bs} and can be neglected, and

$$\sigma_c = \frac{1}{K_1^2 + K_2 f}\left(\frac{1}{3} G \frac{t^2}{S^2} + E\pi^2 \frac{B_n}{1 - \mu^2} \frac{t^2}{L^2}\right) \qquad (3b)$$

for the case when C_{bs} is equal to zero.

In the above equations, K_1^2, K_2, f, B_s, and B_n are dimensionless numbers, numerically equal to i_s^2, i_n, e, C_{bs}, and C_{bn}, respectively, per unit of S and as such are functions of the *form* of the cross-section and not its size.

Making substitutions $t/S = \psi$ and $S/L = \chi$ then Eq. (3a) becomes

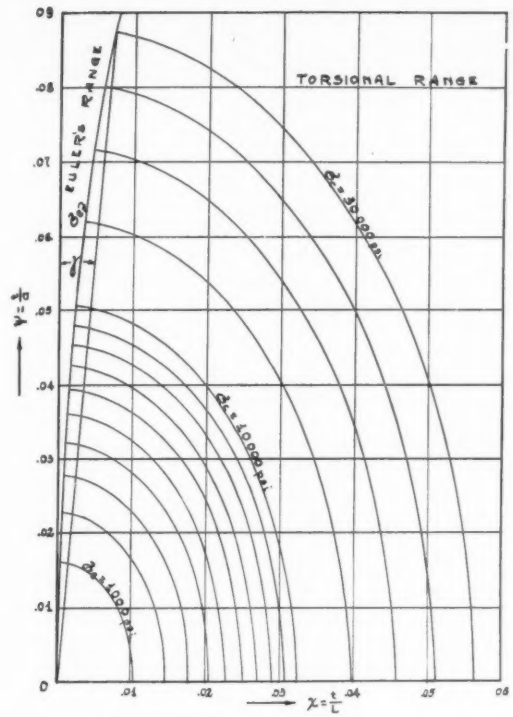

FIG. 1.

$$\frac{\psi^2}{U^2}+\frac{\chi^2}{V^2}=\sigma_e \tag{4a}$$

where U and V are constants for a given material, given eccentricity, and given form of the cross-section. Eq. (4a) is an ellipse with major and minor semi-axes equal to $U\sqrt{\sigma_e}$ and $V\sqrt{\sigma_e}$, respectively.

In a similar manner it can be shown that Eq. (3b) is also an ellipse of variable parameters $\psi = t/S$ and $\chi' = t/S$. The fact that the average critical stress has an elliptical relation to certain parameters of the shell is very helpful in the design of these shells.

Examples of the design of equal legged angles and circular arc sections are given below. The following discussion will be limited to cases when the resultant of the external load passes through the center of gravity of the cross-section. This by no means restricts the application of the proposed theory. It can easily be seen from Eq. (1) that if the value of P_e of a concentrically loaded shell is known ($e = 0$) then the value of P_e' for a given eccentricity can be found by proportion.

Design of Equal Legged Angles

It happens that for these sections the torsional-bending constant C_{bs} is equal to zero, therefore, Eq. (3b) must be used.

Choosing a (the length of a leg) as the parameter which defines the cross-section, t the wall thickness, and L the length of the shell. Eq. (3b) becomes[6]

$$\sigma_e=\frac{E\pi^2}{12(1-\mu)^2}\left[\frac{6(1-\mu)}{\pi^2}\frac{t^2}{a^2}+\frac{t^2}{L^2}\right] \tag{5}$$

and with substitutions

$$\frac{t}{a}=\psi;\quad \frac{t}{L}=\chi;\quad \frac{12(1-\mu^2)}{E\pi^2}=U^2;\quad \frac{\pi^2}{6(1-\mu)}=V^2 \tag{6}$$

get

$$\sigma_e=\frac{\psi^2}{U^2V^2}+\frac{\chi^2}{U^2} \tag{7}$$

Ellipse Eq. (7) with semi-major and semi-minor axes $UV\sqrt{\sigma_e}$ and $U\sqrt{\sigma_e}$, respectively, represents the correlation between ψ and χ (or t/a and t/L) for a given critical stress, that is, the coordinates of any point on the ellipse give the values of t/a and t/L for the same critical stress σ_e. Since the scale of the ellipse Eq. (7) is proportional to $\sqrt{\sigma_e}$ a family of ellipses drawn for a number of pre-assigned values of σ_e will cover a whole field from which for given ratios of t/a and t/L only one critical stress can be found.

At the points where the ellipse intersects the χ-axis we have $\psi = t/a = 0$ and since t cannot be zero because t/L is not zero then a must be infinite. Thus from Eq. (5)

$$\sigma_e=\frac{E\pi^2}{12(1-\mu^2)}\frac{t^2}{L^2} \tag{8}$$

or this is the case of an infinite plate of the thickness t and height L subjected to the compressive force σ_e pounds per unit of area at the point of buckling.

At the point when the ellipse intersects the ψ-axis

$$\chi = t/L = 0 \quad \text{or} \quad L = \infty$$

which shows that the critical stress is independent of the length of the column, and therefore the formula breaks down when χ approaches zero.

The limiting value of χ at which Eq. (7) is still valid can be determined in the following way.

Let $P_e = E\pi^2 I/L^2$ be Euler's critical load on the column, when the average Euler's critical stress will be

$$\sigma_e=\frac{E\pi^2a^3t}{2at\ 12L^2}=\frac{E\pi^2}{24}\frac{a^2}{L^2} \tag{9}$$

but

$$\frac{a}{L}=\frac{t}{L}\frac{a}{t}=\frac{\chi}{\psi}$$

and finally

$$\frac{a}{L}=\frac{\chi}{\psi}=\frac{2}{\pi}\sqrt{\frac{6\sigma_e}{E}}=\tan\gamma \tag{10}$$

Thus the limiting boundary of the ellipse of critical stress can be determined by Eq. (10).

On Fig. 1 a family of such ellipses is shown. They are for equal-legged duralumin angles for which E =

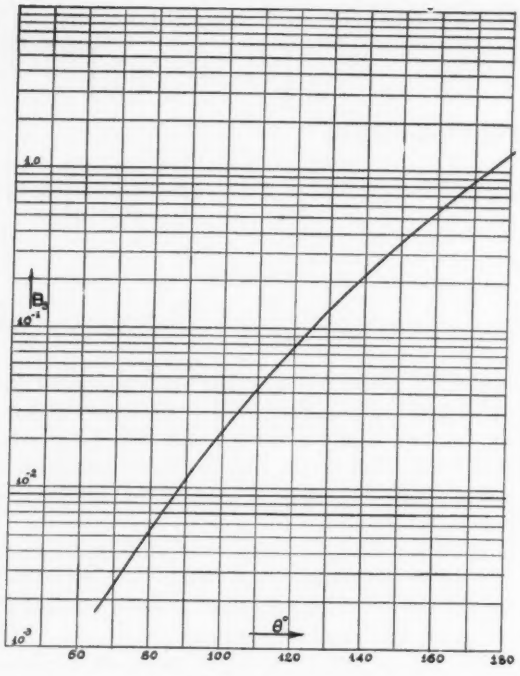

FIG. 2. Coefficient B_s for circular arcs.

10×10^6 lbs./sq.in. and $\mu = 1/3$. It is proposed that Fig. 1 should supersede the present varieties of semi-empirical curves, as for instance, those which are given on Fig. 3 of N.A.C.A. Technical Note 413.

ECONOMICAL SECTION

The torsional critical stress σ_c is *inversely* proportional to a^2 (see Fig. 1 and Eq. (5)). That is, with the decreasing of a the allowable unit stress on the column is increased. However, Euler's critical stress σ_e (Eq. 9) is *directly* proportional to a^2. That is, with the increasing of a the allowable unit stress on the column is increased. Since the ideal economical design is that in which a member can be stressed without buckling up to the yield point stress of the material, the most efficient sections will be obtained when the values of the ratios t/L and t/a are falling on the line σ_e. Strict adherence to this rule is not advisable, however, because slight variations in the dimensions of the column may throw it into Euler's region where the critical stresses are falling much more rapidly than they are in the torsional region. Since the ellipses are fairly "flat" near the point of intersection with Euler's curve, an increase in the value of χ will not change the value of the critical stress much, but the shell will be further from the undesirable Euler's range. Thus it is proposed that in the actual design, points just to the right of line σ_e be used, where there is little sacrifice on maximum value of the critical stress (therefore on economy), but gain on rigidity (or safety).

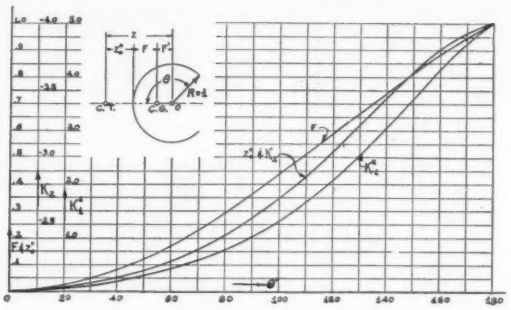

FIG. 3.

DESIGN OF CIRCULAR ARC SECTIONS

The design of these sections should be carried out by means of Eq. (3a).

If the section is defined by $2R\theta$ where 2θ is the central angle and R the radius of the arc, then Eq. (3a) will not change its form except that R must be substituted for S. The geometrical constant will be

$$K_1^2 = z^2 - 2zF' + 1 \tag{11}$$

$$K_2 = -2z \tag{12}$$

$$B_s = \frac{1}{3}\theta^2 - 2\frac{(F' - \cos\theta)^2}{1 - F'\cos\theta} \tag{13}$$

in which

$$F' = \frac{\sin\theta}{\theta} \tag{14}$$

and

$$z = 2\frac{\sin\theta - \theta\cos\theta}{\theta - \frac{1}{2}\sin 2\theta} \tag{15}$$

the values of these constants as the functions of θ are plotted on Figs. 2 and 3.

Since the values of coefficients K_1^2, K_2, and B_s vary with θ, one diagram of the ellipses of critical stress will not cover all circular arc sections, but for any given θ such a diagram can easily be constructed.

EXPERIMENTS

In order to check the type of buckling of thin shells as well as the critical compressive load that is predicted by the above theory, a series of experiments were performed on a specially designed testing machine shown on Fig. 4.

Limited space does not permit a detailed description of the testing machine, specimen, technic used, and results of experiments. It must suffice to state that the circular arcs and equal-legged angles of twelve different cross-sections were used. There were twenty-five specimens all of aluminum alloy known as 17ST., varying in length from twenty-four to sixty inches. There were about one hundred separate tests made

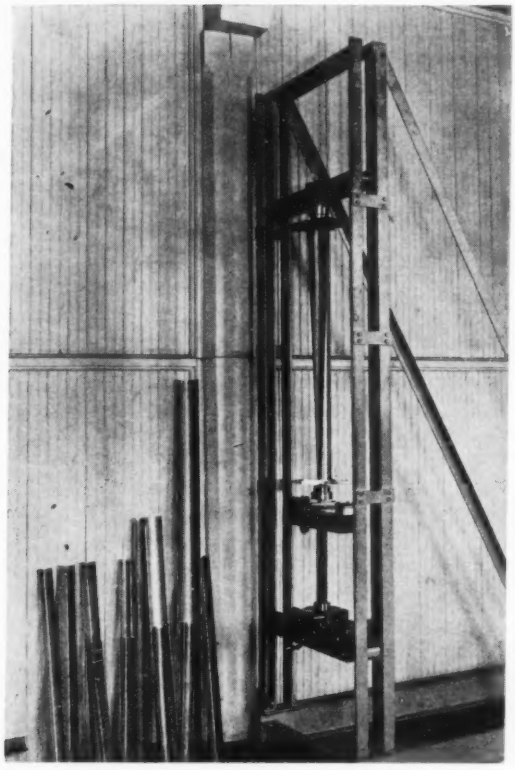

FIG. 4. Testing machine and some of the test specimens.

with different eccentricities of applied load. Examples of the experimental results are given in Tables 1 and 2.

It can be seen from Eqs. (3a) and (3b) that the average critical stress σ_c consists of the sum of two stresses, one which is independent of the length L of the shell, and the other which is inversely proportional to L^2.

Let σ_{c0} be the average critical compressive stress on the concentrically loaded shell (that is when $f = 0$), σ_1 be the stress independent of L (first term in the brackets) and σ_2 be the stress which is influenced by the length of the shell (second term in the brackets) then

$$\sigma_{c0} = \sigma_1 + \sigma_2$$

The values of σ_1 and σ_2 for each specimen tested are given in the tables, their relative importance on the total critical stress can be followed up.

From the discussion of the ellipse of critical stress it can easily be deduced that the economical shells are those for which σ_2 is very small compared with σ_1.

The average buckling stress under which the shells actually fail is given under the heading P/A and the percentage of error was computed by

$$\text{Err. } \% = \left(1 - \frac{P}{A} \cdot \frac{1}{\sigma_c}\right) \times 100$$

TABLE 1

$1^5/_8 \times 1^5/_8$ Angles

$a = 1.625$ in. $\quad t = .071$ in. $\quad A = .2307$ in.^{2}

$L = 56.25$ in. $\sigma_1 = 7000$ $\sigma_2 = 14$ $\sigma_{c0} = 7014$ $\sigma_e = 3130$

$3\sqrt{2f}$	P/A	σ_c	Error %
$-.577$	1820	16500*	
$-.115$	2242	7900*	
.346	3460	5200*	
.808	2242	3870*	
1.264	2740	3080	1.1

$L = 36.06$ in. $\sigma_1 = 7000$ $\sigma_2 = 38$ $\sigma_{c0} = 7038$ $\sigma_e = 8500$

$3\sqrt{2f}$	P/A	σ_c	Error %
$-.115$	6150	7950	22.5
.346	4920	5230	5.9
.808	3790	3890	2.6

$L = 23.2$ in. $\sigma_1 = 7000$ $\sigma_2 = 92$ $\sigma_{c0} = 7092$

$3\sqrt{2f}$	P/A	σ_c	Error %
.346	5050	5260	4.0

* Load removed at the pronounced Euler's deflection with no apparent twisting.

TABLE 2

$R = 1.00$ in. $\theta = 134°$ $t = .0493$ in. $A = .230$ in.^{2} $B_s = .165$

$L = 66.0$ in. $\sigma_1 = 1090$ $\sigma_2 = 1380$ $\sigma_{c0} = 2470$

$K_1^2 + K_2 f$	P/A	σ_c	Error %
3.73	1910	1825	-4.6
2.493	2735	2730	-0.5

$L = 42.2$ in. $\sigma_1 = 1090$ $\sigma_2 = 3385$ $\sigma_{c0} = 4475$

$K_1^2 + K_2 f$	P/A	σ_c	Error %
3.730	3240	3290	1.5
3.318	3745	3700	-1.2
2.905	4170	4220	1.2
2.493	4690	4920	4.7
2.080	6170	5900	-4.6
1.675	7170	7310	1.9
1.255	8570	9780	12.4

$L = 24$ in. $\sigma_1 = 1090$ $\sigma_2 = 10{,}500$ $\sigma_{c0} = 11{,}590$

$K_1^2 + K_2 f$	P/A	σ_c	Error %
3.730	9560	8520	12.2

CONCLUSION

Before experiments were performed it was difficult to predict how the specimen would behave below or at the critical load, especially the effect of initial eccentricities in the specimen itself, eccentricities of the applied load, and the end conditions would have on the ultimate load.

FIG. 5. Typical failure of an equal-legged angle.

FIG. 6. Typical failure of a circular-arc shell.

Some experimentalists[7,8] took many precautions in measuring the lateral deflections and removing them by minute adjustments of the eccentricity of the applied load. They also measured the length of the specimen very carefully, even correcting its length with Kármán's formula for effective length of prismatic bars.[9] A similar technique was tried in this case but was soon discarded as impractical and meaningless.

In spite of the facts that the slide rule was used in computations, that the eccentricity was measured within $^1/_{32}$ in., that the specimen had a noticeable initial crookedness and some variation in wall thickness, it is remarkable that the theoretical and actual critical loads are in such close agreement. One explanation could be offered, that is, if it is established that a shell *is in the range* of torsional buckling, the smaller the value of the parameter χ is the smaller will be that part of the total critical stress which is influenced by the length of the shell, thus the compressive critical stress will be proportional only to the torsional rigidity of the shell. If this is the case, then the conditions at the supporting ends of the shell should have no direct influence on its load-carrying ability. However, it should be kept in mind that by partially fixing the ends the value of Euler's critical stress (σ_e) is increased, thus widening the range of the torsional buckling and consequently gaining on the economy of the design. It must be emphasized that the author's experiments were not made to prove this hypothesis, however, if the experiments would conform to these deductions the design of economical stiffeners should be still further simplified.

The theory presented in this paper is not an exact solution of the problem of torsional stability of thin shells in the same sense as Euler's equation is not an exact solution of the stability of prismatic bars. However the degree of approximation is well within the limits of the error allowed by the practical designer. The exact solution of this problem is not yet known.

During the test a little progressive twist in the column as the load was increased could be noticed. This twist probably amounted to only a few degrees just before the specimen failed, but apparently had a

definite relation to the applied load. The values of the angle of twist correlated with the compressive load may provide the key to the exact solution.

The author regrets that he did not provide the means of measuring this torsional deflection, but limited time did not permit the redesign of the testing machine.

References

[1] Abstract from a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in the University of Michigan. (*The paper deals only with open cylindrical sections—The Editor.*)

[2] See Z. Math. Physik, Vol. 58, page 343, 1910, or *Proceedings of the Third International Congress for Applied Mechanics*, Vol. III, pp. 1–7, Stockholm, 1930.

[3] Leduc, Rene, *Proceedings of the Third International Congress for Applied Mechanics*, Vol. II, pp. 52–57, Stockholm, 1930.

[4] Wagner, H., *Verdrehung und Knickung von offenen Profilen*, 25-Jahre Technische Hochschule, Danzig.

[5] Wagner, H., and Pretschner, W., *Luftfahrtforschung*, pp. 174–180, Munich, December 5, 1934. For english translation see N.A.C.A. Technical Note 784.

[6] This equation, which has been derived on the basis of Wagner's theory and corrected for Poisson's ratio, coincides exactly with the equation obtained by S. Timoshenko (see reference 2), in which he considered the problem of stability of L-sections as equivalent to two plates hinged at the ends and the common edge, and free at the other.

[7] Bridget, F. J., Jerome, C. C., and Vosseller, A. B., *Experiments on Buckling of Thin-Wall Constructions*, Transactions of A.S.M.E. (APM. 56-6), pp. 569–578, August, 1934.

[8] Parr, W. S., and Beakley, W. M., *An Investigation of Duraluminum Channel Section Struts Under Compression*, Journal of the Aeronautical Sciences, Vol. 3, No. 1, pp. 21–25, September, 1935.

[9] Kármán, Th. von, *Untersuchungen über Knickfestigkeit*, Mitteilungen über Forschungsarbeiten, Vol. 81, Berlin, 1910.

Additional References—N.A.C.A. Report 502 and N.A.C.A. Technical Memorandum 807.

Institute Notes

Meetings

December 17, 1937. The Wright Brothers' Lecture by Professor B. Melvill Jones of Cambridge University, England. Annual Dinner and Honors Night. Conferring of Honorary Fellowships, presentation of Daniel Guggenheim Medal, Sylvanus Albert Reed Award, and Lawrence Sperry Award. Hotel Biltmore, New York.

December 21, 1937. Wright Brothers' Lecture repeated by Professor B. Melvill Jones at the California Institute of Technology, Pasadena, California.

December 27–30, 1937. Institute Meeting as part of Annual Meeting of the American Association for the Advancement of Science, Indianapolis, Indiana.

January 24–27, 1938. Annual Technical Meeting of the Institute of the Aeronautical Sciences, Columbia University, New York.

February 11, 1938. Institute of the Aeronautical Sciences, Los Angeles Branch Annual Meeting Review, Los Angeles, California.

June 28–30, 1938. Institute Meeting as part of Summer Meeting of the American Association for the Advancement of Science, Ottawa, Canada.

September 12–16, 1938. International Congress for Applied Mechanics, Massachusetts Institute of Technology and Harvard University, Cambridge, Massachusetts.

The Institute is holding five important meetings during December and January.

The First Wright Brothers' Lecture on "Boundary Layer Experiments in Flight" by Professor B. Melvill Jones, Francis Mond Professor of Aeronautical Engineering and Member of the British Aeronautical Research Committee, was delivered at Columbia University on December 17.

In the January issue of the Journal the lecture will be printed in full with digests of the discussion by B. C. Boulton, of The Glenn L. Martin Company; Dr. Hugh L. Dryden of the National Bureau of Standards; Dr. W. F. Durand of Stanford University; Dr. J. C. Hunsaker of the Massachusetts Institute of Technology; Dr. George W. Lewis of the National Advisory Committee for Aeronautics; Igor I. Sikorsky, Sikorsky Aircraft Division, United Aircraft Corporation; Eastman N. Jacobs, National Advisory Committee for Aeronautics, and T. P. Wright, Curtiss-Wright Corporation.

Professor Jones will repeat the lecture at the California Institute of Technology on December 21. A report of the discussion after this lecture will also appear in the Journal.

The proceedings of Honors Night on December 17 at the Hotel Biltmore will also be reported in the Journal for January. The program for this meeting commemorating the thirty-fourth anniversary of the first flight of the Wright Brothers follows:

Introduction . . . . . Dr. Clark B. Millikan
President, Institute of the Aeronautical Sciences

Chairman:
Hon. Harry F. Guggenheim

Presentation of Honorary Fellowships to . . . . . Prof. B. Melvill Jones and Glenn L. Martin

The Guggenheim Medal . . . . *by* T. P. Wright
President, The Daniel Guggenheim Medal Fund

Presentation of the Guggenheim Medal to . . . Dr. Hugo Eckener
by Dr. Harvey N. Davis
President, The American Society of Mechanical Engineers

Acceptance of the Guggenheim Medal on behalf of Dr. Eckener
by Commander C. E. Rosendahl, U.S.N.

Presentation of the Sylvanus Albert Reed Award to E. N. Jacobs
by Hon. Edward P. Warner

Presentation of the Lawrence Sperry Award to C. L. Johnson
by Elmer A. Sperry, Jr.

Presentation of 1937 Institute Fellowships . . . . . (*Names of recipients to be announced*)

Presentation of Honorary Memberships to
Dr. Lyman J. Briggs, *Director*, National Bureau of Standards
Rear Admiral A. B. Cook, *Chief*, Bureau of Aeronautics, Navy Department
Fred D. Fagg, Jr., *Director of Air Commerce*, Department of Commerce
Dr. W. R. Gregg, *Chief*, U. S. Weather Bureau
Hon. Harry F. Guggenheim
Dr. G. W. Lewis, *Director of Research*, National Advisory Committee for Aeronautics
Major General O. Westover, *Chief*, Air Corps, War Dept.

The Wright Brothers . . . *by* Dr. Wm. F. Durand
Professor Emeritus, Stanford Univ.

On December 28 and 29, the Institute is holding a session at the Annual Meeting of the American Association for the Advancement of Science at Indianapolis. The program follows:

Tuesday, December 28, 1937—2 P.M.

O. T. Kreusser, Allison Engineering Co., *Chairman*

D. W. Tomlinson, Transcontinental & Western Air, *Nearing the Stratosphere.*

Major A. W. Stevens, U.S.A., Materiel Division, U. S. Air Corps, *Problems of Stratosphere Exploration.*

Edward Minser, Transcontinental & Western Air, *Further Investigation in the Icing of Aircraft.*

Professor Bradley Jones, University of Cincinnati, *A Special Application of Photoelasticity in Study of Stresses.*

Wednesday, December 29, 1937—10:30 A.M.

Dr. W. F. Durand, Stanford University, *Chairman*

J. G. Flynn, American Airlines, *Radio Direction Finding in Transport Aircraft.*

Professor M. J. Thompson, University of Michigan, *Some Unsolved Problems in Aerodynamics.*

William Littlewood, American Airlines, *Developments in Air Transport Design.*

Colonel A. D. Tuttle, Medical Director, United Air Lines, *Aviation Medicine and Some of Its Current Problems.*

Following these four meetings will be the Annual Technical Meeting at Columbia University on January 24–27. The program has been extended this year to four days, the last day being devoted to Air Transport. Instead of a formal Annual Dinner there will be a Smoker for which an interesting and amusing program is being arranged.

Institute Emblem

At the request of many members an emblem of the Institute has been prepared. It was the desire of the Council to make the button representative of the Institute activities and therefore the perfect streamline form with the air flow around it was selected. Three types have been made: Gold and Black for Honorary Fellows and Fellows, and Chromium and Black for all other members except Student members, who will wear White and Chromium. The price of student emblems will be 50¢, postage prepaid. For all others, the price will be $1, postage prepaid. Stamps, bills, or checks will be accepted for payment. Members agree, as part of their applications, to wear the emblem only so long as they are members of the Institute in good standing.

Student Branches

University of Detroit. The first fall meeting of this Student Branch of the Institute was held in the Engineering Building of the University on Tuesday, October 19. The program of the meeting was divided into two parts. In the first part of the meeting pictures of recently developed aircraft were shown which included all types of aircraft, from the novel versions such as the tailless types, to the latest four-engined "flying fortresses." Pictures of the racing airplanes flown in this year's National Air Races were also shown. Professor Peter J. Altman pointed out the interesting aerodynamic and structural facts of each of the airplanes and answered questions with regard to them as they were shown. The second part of the program consisted of showing four reels of motion pictures, obtained through the courtesy of the Soaring Society of America. These pictures, which were taken in Germany, South America, and the United States, explained the various stages of training a glider pilot has to go through before he becomes an advanced soaring pilot. The last of the reels was devoted to emphasizing the danger involved in stunting gliders.

Georgia School of Technology. The first regular meeting of the School year of this Student Branch of the Institute was held on Friday, October 1, in the Aeronautical Building of the School. After the completion of routine business, members were given demonstrations of the operation of the research equipment in the large and small wind tunnels and the engine laboratory. Dr. R. H. Mills gave a brief explanation of the principles of the slotted and flapped wing, illustrating the salient points in his explanation by a model of a high-wing cabin monoplane equipped with a slotted and flapped wing which was in position in the large tunnel. The following officers were elected: President, W. H. Paxton, Jr.; Vice-President, W. G. Kirst, Jr.; Treasurer, P. L. Martin; Secretary, Walter Castles, Jr.

University of Michigan. The first meeting for the academic year 1937–38 of this Student Branch was held Thursday, October 7. Following the opening of the meeting by Chairman Farrah, Professors Thompson and Pawlowski of the Aeronautical Engineering faculty were introduced to the group. Professor Thompson summarized the history of the University of Michigan Aero groups and the present Student Branch of the Institute, and also told of the organization of the Institute. Officers were elected, Professor Thompson being unanimously elected Honorary Chairman, and Marvin Michael, a graduate student, Treasurer. Following the election of officers, Professor Thompson discussed new developments under way in the various laboratories and plants which he had visited during the summer holiday.

A second meeting of this Student Branch was held Thursday, October 28, in the East Engineering Building of the University. At this meeting Julius Jaeger was elected as Treasurer, and Joseph Robinson as Vice-Chairman. Following these elections, George Haldeman, inspector for the Bureau of Air Commerce stationed at Wayne County Airport, was introduced as the speaker of the evening. Mr. Haldeman described his flight across the Atlantic Ocean with Ruth Elder in 1927 and made his talk interesting by relating his various preparations and experience, and by contrasting the equipment available then with that used today.

University of Minnesota. A first meeting of the School year of this Student Branch was held Thursday, October 7, in the Auditorium of the Main Engineering Building, about 90 students attending. At this meeting the purposes, aims, and organization of the Institute were explained and discussed. Faculty members present were: Professor John D. Akerman, Head of the Department of Aeronautical Engineering; Howard W. Barlow, Associate Professor; Dr. Jean Piccard and Mrs. Jeanette Piccard, Edward E. Brush, and Gordon H. Strom.

A second meeting of this Branch was held on Wednesday, October 20, at which Howard Barlow, Associate Professor of Aeronautical Engineering, spoke on "The National Air Races." Mr. Barlow, who was on the Official Timing Staff, explained the method used in timing the races. He also reported on the results of the various races and on the construction of the airplanes entered. Other members of the faculty present were Professor John D. Akerman, and Edward E. Brush.

A third meeting was held November 10 in the Minnesota Union. The speaker of the evening, Henry W. Salisbury, was formerly an instructor in Aeronautical Engineering at the University of Minnesota, and is at present Engineer for Northwest Airlines, Inc. Mr. Salisbury spoke on the new Lockheed 14, describing its new features.

North Carolina State College of Agriculture and Engineering. An organization meeting of this Student Branch was held on September 28. Officers elected were: L. R. Parkinson, Honorary Chairman; L. H. Abraham, Chairman; R. Loos, Vice-Chairman; and J. Leet, Secretary.

A second meeting of this Student Branch was held on Tuesday, October 12. At this meeting H. C. Gerrish, Chief of the Engine Analysis Section of the N.A.C.A., addressed the meeting and told of the development of the Langley Memorial Laboratory from 1915 to the present. Following his talk a four-reel series of motion pictures was shown on work of the N.A.C.A. The first series showed the towing of pontoon floats in the towing basin; the second the flow of air over various wing sections in the N.A.C.A. smoke tunnel and the effect of varying their position; the next showed photographs of the explosion of fuel in injection fuel engines, the photographs being taken at a speed of one twenty-five thousandths of a second; and the last series pictured a tailspin and its correction by use of a model in the vertical wind tunnel.

A third meeting of this Student Branch was held on October 26. At this meeting, the following Committees were appointed: Program, Papers, Publicity, State College Engineers Fair Committee, and a Committee on Flying Activities. The speaker of the evening, H. Finkelstein of the Radio Staff of the Bureau of Air Commerce, was introduced. Mr. Finkelstein spoke on the equipment now in use to further safety in the airways and also of the new equipment to be installed at the Raleigh Municipal Airport.

This Student Branch held its last meeting of the year on Tuesday, November 23. Following the business of the meeting, two N.A.C.A. motion pictures were shown; the first on "The

Fundamental Theory of Air Flow and Air Flow Separation," and the second on "The Effect of Fuel Ratio on Ignition in a Compression-Ignition Engine."

Rensselaer Polytechnic Institute. This Student Branch of the Institute held its first formal meeting of the term on Thursday, September 30. Dr. Paul E. Hemke, Head of the Aeronautical Department, was the guest speaker, and spoke on "The Organization of the Institute of the Aeronautical Sciences."

Necrology

The death is announced of Prof. Dr. Fr. Ahlborn of Hamburg on October 27, 1937 in his 80th year.

Dr. Ahlborn was a pioneer in the application of photography to the study of fluid motion. In particular, he obtained beautiful photographs of the flow of water carrying brightly illuminated particles of boiled sawdust. His two-dimensional flow patterns were so precise that the tracks made by the lighted particles during the time of exposure could be interpreted as velocity vectors. The photographs showed, fort he first time, the mechanism of flow separation and eddy formation. Later his work was useful in giving a physical picture of the boundary layer theory, the absolute and relative stream lines about an airship shape, and the vortex theory of propellers. For three-dimensional flow problems, Dr. Ahlborn used a stereoscopic camera and other methods which might be revived.

Dr. Ahlborn was an amateur, in the best sense, and carried out his experiments with homemade equipment in his spare time. Such an individual worker can, at times, illuminate a field in which more orthodox analysis makes little progress. This was the case with Ahlborn's early work when the mathematical analysis was pretty well tangled up between real and ideal fluids. Ahlborn, in 1902, made it clear that real fluids behaved like ideal fluids under certain circumstances and his subsequent work made the assumptions of Prandtl's boundary layer theory seem not unreasonable.

Dr. Ahlborn gave a set of his flow photographs when the Aeronautical Engineering Course at M.I.T. was being organized in 1913.

J. C. HUNSAKER

Personnel Opportunities

The Personnel Bureau serves organizations seeking to employ aeronautical specialists as well as individual members. The Bureau has been the means of arranging several very successful connections for members.

Any member or organization may have requirements listed without charge.

Available

Airplane engineer with over 20 years' experience in land and seaplane designs, particularly of the most modern and efficient types. Can assume executive responsibility in project and chief engineering positions and is acquainted with military requirements, having spent seven years in the Army and Navy services. Have several valuable patents, one of which is internationally known and in use. Write Box 68, Institute of the Aeronautical Sciences.

Instructor with several years experience in the Aeronautical Engineering Department of a well known University (Aeronautical Engineering Curricula accredited by E.C.P.D.) wishes to make a change in position. Would like to contact colleges needing a man to teach A.E. and allied engineering subjects. Experience includes extensive aerodynamic laboratory research. Degrees held, B.S. in M.E., Aero.E., and M.S. For further details write Box 69, Institute of the Aeronautical Sciences.

Graduate Engineer, B.S., age 27, single, 4 years' aircraft instrumentation experience. Graduate Air Corps Training Center. Transport Pilot (1500 hours) with considerable instrument test flying experience. At present employed but desires a change to a sales and service or a flight test engineering position requiring a combination of broad educational background, personality, and experience in the aeronautical industry. Write Box 70, Institute of the Aeronautical Sciences.

Book Reviews

Mine Host American, by MARK PEPYS, 6TH EARL OF COTTENHAM; William Collins Sons & Company, New York, and Collins, London, 1937; 473 pages, ill., $4.00.

When the Earl of Cottenham came to the United States with letters of introduction from Charles Grey of "The Aeroplane" many aviation friends tried to show him as much of our air endeavor as he had the time to see. His family name, Mark Pepys, immediately recalled the immortal diarist Samuel Pepys, of which family he is the head. His cordiality soon overcame the difficulty Americans have with titles and soon it was Mark and Clark, Donald and Lester, at his suggestion.

While here he wrote of his impressions of the United States for several English papers. With these as memoranda, a book of over four hundred pages of the most delightful and informed comment on American life and customs has resulted.

The book is divided into two logical parts; the first being a description of experiences on a fast but circuitous automobile trip from New York to Los Angeles, and the second of his trip back by air. No book about air travel that has been received has covered the subject from a similar viewpoint. Aside from the clarity of the style and the accuracy of presentation, almost every page contains some parenthetical comment that could only come from an intelligent observer. Things which seem commonplace and pass unobserved to Americans are picked up by the author and given an interest which makes them seem entirely new.

In Los Angeles, several well known persons in aviation pass under the friendly critical eye of the Earl. His impressions of Southern California are refreshing in their naive presentation.

Of the flights to San Francisco and back to New York from Los Angeles no detail escaped the eye of the distinguished passenger who has been a pilot for many years.

The book aroused so much interest in England that it is being placed on sale in this country and may be obtained on order from any bookseller. No book on travel in the United States written by a foreign guest will give such pleasurable reading to aeronautical specialists as "Mine Host America."

LESTER D. GARDNER

Airplane Maintenance, by JOHN E. YOUNGER, ALLEN F. BONNALIE, AND NAINE F. WARD; McGraw-Hill Book Company, New York, 1937; 353 pages, ill., $3.00.

No more practical book than this could be made available for the airplane mechanic. It is written in straightforward style and will be a standard reference work at repair stations and airplane maintenance shops, as well as at airports where repair and overhaul work is such an important part of the revenue.

The authors are experienced teachers who have, through lecturing, learned to present technical subjects in an understandable manner. Practical information on materials and construction of airplanes and parts, repair shop equipment and methods, servicing, testing, etc., are all given careful and well illustrated treatment. More than fifty specialists have assisted the authors in making this book authoritative. The bibliographies and questions and answers make the chapters adaptable for use in airplane schools. Not only will the mechanic find the book of value but the private owner will learn more about how his airplane is made and how to check its condition. It is a standard book in its field.

Circling the Caribbean, by TOM MARVEL; Harcourt, Brace and Company, New York, 1937; 302 pages, $2.50.

No traveler over the lines of Pan American Airways will ever have reason to complain that he cannot find information as to what to do, what to see, whom to meet, what to eat and drink, and how to behave. A five foot shelf of books written by returned passengers is being filled by new additions which seem to appear almost monthly. The latest, by Tom Marvel, who spent two and one-half months in flying from port to port around the Caribbean, will answer many of the above questions for the passenger who is planning such a trip or those who have to do their travelling vicariously. Written in a breezy style, it makes a splendid guide to the "American Mediterranean."

Last Flight, by AMELIA EARHART; Harcourt, Brace & Company, Inc., 1937; 226 pages, $2.50.

The principal actuating motive of Amelia Earhart behind her great flights is clearly shown in a paragraph of a letter written to her husband before a hazardous flight. She wrote: "Please know I am quite aware of the hazards. I want to do it because I want to do it. Women must try to do things as men have tried. When they fail, their failure must be but a challenge to others." This note of feminism, of which Amelia Earhart was one of the leading proponents in this country, is a thread which binds the story of her many flights together.

This book, which was intended to be published soon after her return from the tragic around-the-world exploit, gives the philosophy as well as the romance of this great airwoman's flying career. It is written in a style that is both modest and stimulating. It will undoubtedly cause thousands of young women who are anxious to escape from a prosaic existence to attempt to seek fame, fortune, and fun from flying.

No one can read the story of her career as it unfolds, from a settlement worker, through the first Atlantic Crossing by a woman; the non-stop solo transatlantic hop; the Hawaii episode; the Mexico City flight, and culminating in the last great globe circling attempt, without admiring the casual courage behind it all. Determination, organization, and patience all entered into the composite character of Amelia Earhart. But always there was the smiling at fate and an acceptance of the inevitable should it come.

Technically, Miss Earhart always wanted the best, whether it was airplanes, engines, instruments, or even men associates. And she was gracious enough to give credit to all things and persons who aided her to achieve fame.

Amelia Earhart achieved her objective in life even though she paid for the success with her life. She wanted to demonstrate to women that they could have careers which are often exclusively associated only with masculine courage and fortitude. This she did in a way that could not have been accomplished in any less spectacular profession than aviation. Every move she made was news, and news created interest, and the result was that every woman gloried in her accomplishments. And with it all she never lost a feminine charm which brought her friends wherever she went. Her book will always stand as her best memorial.

If War Comes, by R. ERNEST DUPUY AND GEORGE FIELDING ELIOT; The Macmillan Company, New York, 1937; 369 pages, $3.00.

For anyone interested in what may happen to this troubled world in the future there will not be a dull page in this disturbing book. There is so much sensational writing about new methods of warfare that it is a relief to read of tanks, gas, aircraft, and submarines from the viewpoint of the strategist and tactician. An American artillery officer and a former officer in the military intelligence reserve have prepared a military estimate of the forces now stirring in Europe and the Far East. They attempt to forecast conditions in the next war and answer many questions that are uppermost in the minds of all who have apprehensions as the the future of world civilization.

The parts of the book dealing with aircraft will be of the greatest interest to readers of the Journal. The characteristics and military and naval employment of all types of service aircraft are described from the expert's point of view. The authors give credit to Brigadier General Frank P. Lahm for his assistance in preparing the chapter on air power. In a subject as controversial as the potentialities of aircraft differences of opinion are to be expected, but it is evident that the authors have tried to steer a middle course. They have read carefully the best books on the use of air power and have restated the problems in simple terms which a layman can grasp. To those who know what the future developments in aircraft will be, the book does not go far enough but for the present types it reflects the opinion of the military and naval general staffs.

A large part of the public has been indoctrinated with the idea that aircraft are being built for defense purposes. While this is fundamentally true it is well to bear in mind a characteristic of air power expressed so well by the authors. "The air force which adopts a defensive *attitude*, a defensive *spirit*, or permits itself to be forced into one, is in the end an air force defeated."

The chapter on aircraft is divided into three parts: "The Coming of Air Power," "The Instruments of Air Power," and "The Mission of Air Power." In the chapter on sea power the employment of naval aircraft is considered from the viewpoint of the Navy. Additional chapters on the effect of the war on civilian populations, propaganda, and a concise statement of the possible war objectives of Germany, Japan, Russia, Italy, Great Britain, France, and the United States, make the book indispensable for those who wish to be broadly informed on the undercurrents motivating the statesmen in all parts of the world.

Air Navigation (British Empire Edition), by P. V. H. WEEMS; McGraw-Hill Publishing Company, Ltd., London, 1937; 490 pages, ill., 30s.

The indebtedness of navigation to Lieutenant-Commander P. V. H. Weems has been materially increased by the British Empire Edition of his Air Navigation. The American edition appeared in 1931, and has been valued by all engaged in aviation.

There are four methods of determining the position of aircraft, namely air pilotage or the observation of landmarks, dead reckoning, radio, and celestial navigation. As three of these are used at sea, the marine navigator will find much that is inspiring. Although air navigation in its early days was based on the methods used in marine navigation, it has, in many cases, outrun its master, and today the former master is learning from the pupil. There is, however, one fundamental difference between the problems facing the two types of navigators. If a ship is in fog in a dangerous area, it can go slowly or even remain stationary. An airplane must keep moving, and can do so only as long as its fuel lasts.

The early chapters on maps and compasses will be read with interest. The use of the gyro compass in its azimuth-seeking form is not feasible in the air, but gyroscopic instruments are used in maintaining level flight, for maintaining a fixed direction for say 15–30 minutes, and to indicate turns. The "automatic pilot" which operates all the controls of an airplane, is controlled by two gyroscopes. The advantages of repeater dials, usually associated with gyroscopic compasses, are however available from the Holmes Telecompass, an aperiodic magnetic compass.

The practice of dead reckoning is much more difficult for the aviator than for the navigator. The medium in which the navigator moves, namely the water, is subject to the movement known as currents, but the effect of this movement can be estimated with reasonable certainty. The effect of movement in the aviator's medium, or, in other words, the effect of wind, is much more pronounced, and is difficult to measure. Hence the need for the other methods of determining position is greater.

Radio is used more in aviation than in navigation, partly because (when available) it affords the best means of determining position when the ground and the stars cannot be seen. It is invaluable for conveying information about the weather, on which the aviator is very dependent.

The navigator will be particularly interested in the application of celestial navigation. The first difficulty in the air is the usual absence of a natural horizon, or, if this is available, the uncertainty in the dip due to lack of knowledge of the exact height above this horizon. This has been met by the introduction of bubble sextants, which contain their own horizon, and so eliminate dip. On the other hand, the sensitivity of a bubble sextant is less than that of the horizon sextant, and, further, it is subject to large and uncertain acceleration errors due to changes in the velocity or direction of the observer. By taking the mean of say 10 observations, it is possible to measure an altitude to within about 5′. Bubble sextants that will automatically record the mean of six settings are now being developed.

A second difficulty arises from the fact that, during the daytime, only one heavenly body—the sun—is usually available. The marine navigator gets his fix by making two observations of this body several hours apart, and allowing for the run of the ship between the observations. The air navigator cannot afford to wait even one hour before determining his position; even if he could, he cannot estimate his run with sufficient precision, because the effect of wind cannot be measured accurately. It is likely that every effort will be made to observe the Moon, Venus, and Jupiter also during daylight hours. A radio bearing can be crossed with a position line derived from an observation of a heavenly body. Failing those, the most probable position of the plane is the foot of the perpendicular from the dead reckoning position (assuming that it has been carefully computed) to the position line given by the Sun or other heavenly body.

Weems appears to have been the first to advocate the tabulation by the ephemerides of the Greenwich hour angle (in arc) of all heavenly bodies instead of their right ascension. He was responsible for its adoption in the *American Nautical Almanac*, and it has recently been announced that a British *Air Almanac*, now in preparation for 1938, will also adopt this idea. This saves all conversion from time to arc or vice versa, and eliminates the need for any knowledge of right ascension, sidereal time, first point of Aries, or equation of time. As an accuracy of 1′ suffices in an *Air Almanac*, interpolation does not present serious difficulties. With this form of tabulation the determination of a local hour angle consists in extracting the G.H.A. (in arc) from the almanac for the G.M.T. of observation, and applying the longitude (in arc). Trigonometrical tables with the argument in time cease to be necessary—or indeed any knowledge of the relation between time and arc.

A full discussion is given of mechanical and tabular methods of solving the spherical triangle. For air navigation, and for most purposes in marine navigation, the use of an assumed position that is an integral degree of latitude and whose longitude is such that the local hour angle is an integral degree, is permissible, and enables considerable help to be afforded by special tables. The longer intercepts thus arising are a minor drawback compared with the diminished calculation and interpolation.

For star work Weems advocates the use of *Star Altitude Curves*, which are really position lines for pairs of stars. By plotting simultaneous altitudes of a pair of stars, the latitude and local sidereal time can be read immediately. The admitted disadvantages, however, seem likely to prevent these curves from becoming adopted universally; they are expensive, are restricted to chosen pairs of stars, and soon become out of date because of precession.

A more effective means of reducing computation in the air is the use of precomputed altitude curves, showing, for a particular flight and for the chosen heavenly bodies, the altitude plotted against time, and computed on the assumption that the aeroplane follows a predetermined course at a predetermined rate. If an observation is made in the air, it is plotted on this curve. The vertical distance between the plotted point and the altitude curve is the intercept; hence the position line can be plotted immediately. The difference between the plotted point and the curve can often be interpreted pictorially, according to the direction of the heavenly body, and any further drawing avoided.

The book closes with a 100 page chapter on Meteorology, written by Dr. Sverre Petterssen, of Bergen, an international authority. This gives a good insight into meteorological phenomena, the preparation of weather maps, and short-range forecasting.

In a special pocket at the end is a star map of a somewhat novel character, showing all stars down to the third magnitude and the brighter fourth magnitude stars, *i.e.*, the stars required for navigational purposes, and the fainter stars whose configurations serve to identify them.

DR. L. J. COMRIE

Exchanges

The Institute exchanges the Journal with many other aeronautical periodicals. They are kept on file at the Skyport in Rockefeller Center, New York City, where members may read them. As readers of the Journal may wish to subscribe to some of them, a list of these periodicals with their addresses is published here. Information regarding subscription prices may be secured from the Secretary of the Institute.

Aero, Maneesikatu 2, Helsingfors, Finland.

Aero Digest, 515 Madison Ave., New York City.

Aeronautica Argentina, Velez Sarsfield 57, Cordoba, Argentina.

L'Aéronautique, 55 Quai des Grands-Augustins, Paris, France.

L'Aérophile, 7 Rue Sainte-Lazare, Paris, France.

The Aeroplane, 175 Piccadilly, London, W.1, England.

L'Aerotecnica, Via delle Coppelle 35, Rome, Italy.

Les Ailes, 77 Boulevard Malesherbes, Paris, France.

Aircraft Engineering, 2 Bloomsbury Place, London, E.C.1, England.

Air Law Review, Washington Square East, New York City.

American Aviation, Earle Building, Washington, D. C.

Asas, Caixa Postal 1967, Rio de Janeiro, Brazil.

Astronautics, American Rocket Society, 31 West 86th Street, New York, N. Y.

Aviation, 330 West 42nd St., New York City.

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Contact, Fort Lee, N. J.

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AERONAUTICAL REVIEWS

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps.

Aerodynamics

Further Information on Profile Drag Measurements in the Large Wind Tunnel of the DVL. H. Doetsch. New formula for profile drag, developed in a previous paper, is further explained. Brief.

In a second article H. Muttray considers the accuracy of profile drag measurements given by H. Doetsch in the paper under discussion. He compares these measurements with his results at Goettingen as well as with those found by B. M. Jones in England and gives his conclusions on the degree of accuracy obtainable with the pitot traverse method. Luftfahrtforschung, July 20, 1937, pages 367 and 371–372, 1 illus., 1 table.

Investigation of the Single-Stage Axial Blower. P. Ruden. Fan rotor developed in preliminary tests for the new Goettingen wind tunnel has a very high efficiency at the design point (moderate throttling down) and is also capable of being throttled down to a relatively high degree. Extensive theoretical investigations at Hannover into the essential factors to give the required characteristics is described. It was found necessary to drop the usual assumptions of disappearing radial velocities.

First issue—System of free vortices back of the screen; Euler formulas for flow through a screen with infinite number of guides; derivation of flow conditions for flow with and without energy loss; applicability of flow formula to the screen with finite number of guides; graphs for calculating characteristics and efficiency of the screen guides for the case of rotors, characteristics of the screen guides for the case of stationary guide wheels, and energy loss in stationary guide screen; conversion of the single-blade polar to the screen polar; conclusions on the rotors, guide wheels, and rotor construction; and estimation of flow distribution.

Second issue—Experimental and theoretical investigation of three rotors and two guide wheels. Description of test stands and calibration; specifications of rotor and guide wheel; verification of rotor and guide wheel; comparison of theoretical and test results. Very long report of Hannover Technical College and Goettingen Aerodynamic Institute. Luftfahrtforschung, July 20 and September 20, 1937, pages 325–346, 458–473, 42 illus., 5 tables, 83 equations.

The National Physical Laboratory. Pitot-traverse method of drag measurement, compressibility effects at high airspeeds, stability and control, rolling, landing flaps, and tapered wings. Research being carried on in the Aerodynamics Department. Continued. Engineering, October 8, 1937, pages 408–410, 1 illus.

Theoretical Treatment of the Reciprocal Influence of Wing and Fuselage. F. Vandrey. Mutual influence of wing and fuselage is investigated with the help of the potential flow over the fuselage in the field of the lifting vortex. For a spherical fuselage an accurate solution is shown in which an increase in lift is obtained for the wing compared with a larger decrease in lift for the fuselage. For the monoplane having a medium wing of larger span and a fuselage of symmetrical revolution, total lift of fuselage and lift distribution longitudinally for pure axial and diagonal flow are calculated. Downwash induced on the tail by the fuselage is calculated. Goettingen Aerodynamic Institute report. Luftfahrtforschung, July 20, 1937, pages 347–355, 16 illus., 41 equations.

The National Physical Laboratory. Research under way on skin friction, flaps, and thick wings at high Reynolds number is described with details of wind tunnels and other equipment of the Aerodynamics Department. Continued. Engineering, October 1, 1937, pages 381–382, 2 illus.

Aircraft Design

The Economics of Speed. T. P. Wright. It is economically worthwhile to the designer of a large transport to spend as much as $3000 to gain a mile an hour in his experimental machine, and in the final production article a $1000 increase is worthwhile to the operator. Racer record speeds of 500 and 425 m.p.h. for seaplanes and landplanes, and 300-m.p.h. transport cruising speeds are predicted for the next eight years. Formulas are given for airplane operating efficiency factor and air transport efficiency factor. Western Flying, October, 1937, pages 21–23, 34, 1 illus., 6 equations.

Stabilizing Action of the Dihedral Angle. O. H. Lunde. Explanation and sketches serving as a visual conception of what occurs to cause the dihedral angle in the wing to set up forces conducive to static lateral stability. Aero Digest, October, 1937, page 50, 5 illus.

Variable Span and Variable Wing Area. A. E. Parker. For modern aircraft variable span is not a commercial proposition. Flaps appear to be far more effective, and the logical development is the use of assisted take-off. Performance for the airplane fitted with conventional wings and flaps is compared with that for the airplane having variable span and the outboard portion retracted. Investigation of the effect of variable span and variable wing area on top and cruising speeds. To be continued. Flight, Aircraft Engr. Sup., September 30, 1937, pages 13–15, 2 illus., 2 tables.

Aero-Elastic Problems. A. G. Pugsley. General design significance of current research work on flutter and related matters, including trouble arising from flutter, similarity between wing and tailplane problems, and problems involved in terms of wings and ailerons. A stiffness diagram for a typical wing indicates relative stiffness required to prevent wing-aileron flutter, wing flutter, aileron reversal, and wing divergence. Present and future problems are also considered. Appendices comment on variation of wing flutter speed with altitude, and on modern tendency to use wings of low flexural stiffness. Royal Aeronautical Society paper, and discussion. Aircraft Engg. October, 1937, pages 268–275, 9 illus.

Calculation of the Lifting Force on Oscillating Control Surfaces. F. Dietze. Addition to existing work on air forces and air moments of a wing with a control surface oscillating in the ideal two-dimensional flow. Profile of the control surface is assumed to be capable of being represented by a straight line with a single bend. Proportion of lift due to the control surface is calculated for the special case of harmonic oscillation. DVL report. Luftfahrtforschung, July 20, 1937, pages 361–362.

Relative Safety of Multi-Engined Aircraft. J. Stueper. Probability of decreasing the number of forced landings by a distribution of power among a number of engines is investigated. The numerical value is determined for the increase in safety due to the possibility of maintaining flight after engine failures. Influence of the higher load on the remaining operating engines is taken into account. Goettingen Aerodynamic Institute paper. Luftfahrtforschung, July 20, 1937, pages 363–367, 5 illus., 1 table, many equations.

The Two-Dimensional Problem of Wing Vibration. R. Kassner and H. Fingado. Solution to the problems of a two-dimensional wing without ailerons and with no internal damping. Method described is said to be comparatively simple and accurate. Vibrations in still air and in flight, aerodynamic forces, method of calculating critical velocity, examples of the use of charts, mathematical principles, and determination of form of vibration are taken up. Considerations given for the design of wings with desirable vibration characteristics include: rigidity, mass of wing, air density, positions of center of gravity and elastic axes, ratio of bending stiffness to torsional rigidity, and relative inertia radius.

In a second article entitled "The Consideration of Internal Damping in the Two-Dimensional Problem of Wing Vibration," R. Kassner continues this work to take into account internal damping of the wing. Translated from Luftfahrtforschung, November 20, 1936. Jour. Royal Aeronautical Soc., October, 1937, pages 921–944 and 945–952, 26 illus., 1 table, many equations.

The Swing of the Pendulum. Return of the tricycle landing gear, some early designs, and the Curtiss-Courtney amphibian design of 1933. A new Monospar under test, and a General Aircraft, Ltd. model proposed are among the tricycle aircraft illustrated. Flight, October 14, 1937, pages 387–388, 8 illus.

Tricycle Landing Gear. F. E. Weick. Most interesting development in aircraft during the past twelve months is considered to be the application of tricycle landing gear carried on jointly by the Army Air Corps and the Douglas Company. Advantages of this type and references to experiments made by the Air Corps and N.A.C.A. Brief. S.A.E. Jour., October, 1937, page 15.

Stress Analysis and Structures

Buckling of Curved Tension Bay Girders. G. Limpert. Buckling load on curved tension-bay girders with constricted stiffening under transverse load was determined by tests. Webs are bent in a cylindrical curve, flange members lie along the generating axis of the cylinder, and the vertical struts (stiffeners) are located in the direction of the periphery. Tests showed a buckling load of twice that calculated for similarly stiffened flat girders of constant web height. Berlin Technical College report. Luftfahrtforschung, July 20, 1937, pages 356–360, 12 illus., 3 tables.

Towards an Ideal. Jic process applied to producing aircraft spars of Jicwood, to stressed-skin covering with an Onazote stabilizing medium (developed by De Havilland Aircraft Company), and to propeller blades. Different methods are described in detail and unattached Jicwood for covering airplanes is also considered. Physical properties of Halila impregnated wood are compared with those of high-tensile steel, duralumin, Chord Aerolite, and spruce.

Jic process depends essentially upon impregnation of wood with thermoplastic material, and degree of impregnation can be controlled. Jic cement can be used for adhesion, for impregnation, or for producing a very fine hard polished surface. It will join two surfaces perfectly well at temperatures under 100° C. Aeroplane, October 6, 1937, pages 431–432, 2 illus., 1 table.

Very much shorter description. Flight, October 7, 1937, page 363.

Box Beams and Shear Lag. F. R. Shanley. Old engineering trick of cutting something in two and then finding out what is needed to bring it back together is used to throw light on the box beam problem, and to serve as a new method of attack on shear lag. The channel method of attack used to clarify the phenomenon of shear lag offers a method of attacking the complex stress distribution problem. Aviation, October, 1937, pages 34–35, 8 illus.

A Machine and Method of Rolling Sheet Metal to Compound Curvature. A. Klemin. Reduction in number of rivet heads and increase in smoothness from the use of single sheets are two of the advantages in aircraft construction resulting from this method. As the sheets are preformed by controlled pressure and regular rolling process, original strength of the material is more likely to be maintained than in a process involving violent impact.

Professor Klemin considers this method of rolling wide sheets of any desired length to compound curvature a notable advance in airplane production. When the Aluminum Company of America supplies 50-in. x 24 ft. sheets only four will be needed for the entire Northrop Delta type fuselage. Long description of machine patented by Capt. E. B. Cairns. Aero Digest, October, 1937, pages 46, 48, 100, 101, 6 illus.

Technical Notes. Isoflex, the new aircraft material developed by R. Le-Ricolais, is composed of corrugated sheet metal riveted at the cross corrugations. Similar designs have been applied to plywood construction. One consists of two corrugated panels joined along the surface (tubular or semi-tubular panels) and the other of two corrugated panels crossed perpendicularly to the surfaces and joined by tubular rivets. The construction is said to be extremely resistant to buckling as well as to reduce thermal and sound transmission. The two types of plywood construction are illustrated and a few details given. Les Ailes, September 2, 1937, page 8, 2 illus.

Aircraft

The Aeroplanes at Milan. T. James. Design details and armament of the following Italian military aircraft: Bergamaschi (Caproni) CA 310 bi-motored low-wing training bomber (two Piaggio P VII c.16 7-cylinder radials giving 860 total hp., maximum speed 215 m.p.h.). Breda 82 bomber (280 m.p.h.). Cant Z506 bomber version of the famous twin-float monoplane (three Alfa-Romeo R.C. 34 (Bristol Pegasus) giving 2310 total hp., maximum

speed 242 m.p.h.). Caproni CA 134 reconnaissance biplane (Isotta-Fraschini Asso XI R.C. 40 liquid-cooled 900-hp. engine, maximum speed 240 m.p.h.), and the CA. 135 middle-wing monoplane bomber (two liquid-cooled Isotta-Fraschini XI R.C. 40 900-hp. engines, maximum speed 260 m.p.h.) camouflage scheme being referred to. Caproni Vizzola S.A., Breda 65 two-seater fighter or attack low-wing monoplane (Fiat 80 R.C. 41 twin-row 1000-hp. engine, maximum speed 255 m.p.h.). Fiat B.R. 20 bomber (two Fiat 80 R.C. 41 twin-row 1000-hp. radials. maximum speed 267 m.p.h.), as well as the G. 18V. 18-seater passenger carrier with same engine, and the G. 50 fighter (Fiat A.74 R.C. 38 840-hp. radial, maximum speed 293 m.p.h.). Macchi M.C. 99 bimotored bomber flying boat (two Asso XI R.C.40 liquid-cooled engines, maximum speed 180 m.p.h.). Magni Vale single-seater (obsolete Farina engine, maximum speed 161 m.p.h.). Nardi FM-305 (Alfa Romeo 115-1 80-hp. or Gipsy Six, maximum speed 325 km./hr.). Piaggio P.32 middle-wing bomber being built in series for Italian air force (two Piaggio 1000-hp. twin-row radials, maximum speed 260 m.p.h.). Romeo Ro.41 biplane for advanced aerobatic training (Piaggio 7-cylinder 450-hp. radial, maximum speed 210 m.p.h.), and the Ro.51 low-wing monoplane fighter (Fiat twin-row 840-hp. engine). Savoia-Marchetti S.79(three Alfa-Romeo 126 RC 35 750-hp. radials, maximum speed 270 m.p.h.), and the S.83 (maximum speed 267 m.p.h.). Italian touring and transports also described including the Colibri tail-first airplane and the Steffanutti S.S.3 tail-first two-seat pusher.

German airplanes described include: Ago Ao 192 Der Kurier, twin-motored low-wing monoplane for four passengers and crew of two (two inverted 8-cylinder Argus Vee 240-hp. engines, maximum speed 338 km./hr., unusual flaps). Arado AR 96 metal-skinned two-setter multi-purpose trainer (nearly 200 m.p.h. on one 240-hp. Argus). Bayerische Taifun. Focke-Wulf Condor four-motored passenger or freight carrying machine with unusual flaps (four B.M.W. 720-hp. radials, 260-m.p.h. maximum speed, model only shown). Gotha Go.149 small single-engined low-wing monoplane (over 215 m.p.h. with a 240-hp. Argus 10C). Halle Fh 104 low-wing 5-seat passenger carrier (maximum speed 208 m.p.h. with two 240-hp. Hirth HM 508 8-cylinder inverted vees). Henschel Hs.123 biplane fighter dive-bomber (750-hp. B.M.W. 132 engine, maximum speed 220 m.p.h.). Heinkel He 112 all-metal low-wing single-seat fighter (300 m.p.h. on a 680-hp. Junkers Jumo 210 Ea engine) and reference to the Heinkel He 116 four-engined long-range mail carrier (over 200 m.p.h. on four 240-hp. Hirth 8-cylinder engines, range 2800 miles). Junkers Ju 86 "in a new guise as a heavy bomber" with two 750-hp. B.M.W. 132 engines (maximum speed 180 m.p.h.).

The Miles Whitney Straight, Tipsy (32-hp. Sarolea flat-twin engine), and the Zlin XII two-seater monoplane (45-hp. Persy II horizontally-opposed engine) are also described. Very long article. Aeroplane, October 13, 1937, pages 449–455 and 436–437 (photographs), 13 illus.

Milan Review. H. F. King. Comments and a few details, including armament, of the following military aircraft: Caproni Ca.135 bomber (Isotta-Fraschini XI R.C.40 liquid-cooled vee-twelve engines, 1800-hp. combined output, 6338 lb. disposable load, top speed 260 m.p.h., range over 2000 miles). Breda 82 bomber (Fiat A.80 RC-41 two-row 1000-hp. engines, top speed 279 m.p.h.; disposable load 7500 lb., ceiling 31,000-odd ft.). Piaggio P.32 twin-engined bomber (disposable load 7716 lb., top speed 260 m.p.h. with two Piaggio P.XI RC-40 engines). Fiat BR-20 bomber (disposable load 7936 lb., top speed 267 m.p.h. range 5590 miles). Twin Fiat A.80 RC-41 two-radial, (total output 2000-hp.). Junkers Ju.86K bomber supplied to Sweden (useful load 6460 lb., speed 200 m.p.h. with B.M.W. Hornet-type engines). Savoia Marchetti S.79B bomber (more than 300 m.p.h. expected if fitted with 1400-hp. Alfa Romeo engines). Cant Z.506B three-engined bomber-reconnaissance floatplane (Alfa-built Pegasus engines). Macchi M.C.99 bomber flying boat (top speed 177 m.p.h., range 4000-odd miles, disposable load 10,580 lb.).

Fiat G.50 fighter (Fiat A.74 RC.38 two-row 840-hp. engine, useful load 950 lb., top speed 290 m.p.h.). Romano Ro.41 and Ro.51 fighters. Heinkel He.112 fighter (Junkers Jumo 210 inverted vee engine, useful load 1388 lb., top speed 295–300 m.p.h., range 475 miles). Breda 65 fighter (speed 250-odd m.p.h.). Caproni Ca.310 twin-engined trainer of nearly 800 hp. Caproni Ca.134 army cooperation biplane (twin rudders, outlandish undercarriage, 900-hp. Isotta engine, speed over 240 m.p.h.). Nardi F.N.305 fighter-trainer (speed 200 m.p.h.). Transport, training and sport aircraft displayed are also discussed. Flight, October 7, 1937, pages 346–352, 363, 11 illus.

On the Lessons of the Show. C. G. Grey. Mr. Grey's comments on the following as well as on foreign and industrial policies: large number of bimotored high-speed high-powered self-protecting bombers at the Milan Show; preference of Air Ministries for medium bombers and lots of them rather than for big bombers; scarcity of single-seat fighters; epidemic of light and medium two-motored low-wing transport monoplanes; little Ago's unusual flaps; scarcity of airplanes with slots along the leading edges; 62 American exhibits other than aircraft which were preponderantly production tools suggesting an American policy to supply material to Italy; Italian aeronautical industry; criticisms of some German designs with a reference to the Junkers Diesel; and two canards. German as well as Italian products are included in the discussion. Aeroplane, October 13, 1937, pages 441–448, 13 illus.

Atlantic Aspirants. Various types of aircraft which have been used over the North or South Atlantic, are shown in drawings, and the latest ocean aircraft under way or planned in the United States, England, France, Germany, and Italy are discussed. The Boeing 314, Martin 130 Clipper, Lioré et Olivier H-47 and H-49, Loire 102 Bretagne (said to have been disappointing), C.A.M.S. 161 37-ton, Blom and Voss catapultable twin-float seaplanes, Dornier Do.18 twin-Diesel flying boats, twin-Hispano Amiot 370, and new Farman 2220, 2230, and 2231 landplanes are considered briefly. Flight, October 14, 1937, pages 372–376, 16 illus.

Istres-Damascus-Paris Race. Savoia-Marchetti S-79s took first, second, third, sixth, and eighth place in the Race (352, 344, and 342 km./hr. averaged for the winners), the DeHavilland Comet fourth place (314 km./hr. average), the Bréguet Fulgur fifth (294 km./hr. average), the Bloch 160 seventh (273 km./hr. average), and the Farman 2223 ninth (147 km./hr. averaged). Account of the race. Les Ailes, August 26, 1937, pages 4–5, 1 illus.

Algeria

Technical Notes. Helicopter designed by an Algerian engineer, M. H. Bergier, has two 8-meter rotors mounted at the extremities of a chassis, which is formed of hollow beams reinforced by wires. To improve the rotor efficiency of helicopters, a second design is proposed which has eight 3-meter propellers located around the edge of a frame 8.2 meters in diameter. Each propeller is driven by a 12/15-hp. engine. Few details only. Les Ailes, September 16, 1937, page 9, 3 illus.

Czechoslovakia

The Prague Aero Show. F. Wittekind. Characteristics and performance of 25 Czechoslovakian aircraft and 29 aircooled engines exhibited are given in tables. The Aero A-102 single-seater fighter (Gnôme-Rhône 14-N 825-hp. engine, top speed 450 km./hr., photograph but no other data); Aero A-204 transport (two Walter Super-Castor 400-hp. engines, top speed 300 km./hr.); Aero MB-1200 (two Walter K-14 700-hp. engines, a top speed 300 km./hr.); Aero 35 (Avia-Hispano-Suiza 1000-hp. engine, top speed 500 km./hr., but no other data given). Designs of aircraft are discussed. A.T.Z., August 10, 1937, pages 394–397, 4 illus., 2 tables.

Avia 122 Training Airplane. A. Frachet. Czechoslovakian single-seater biplane, designed for training in aerobatics and inverted flight, won the three first places in the Zurich air show. It is powered by a Walter Pollux 350-hp. engine having a special carburetor, and has a maximum speed of 270 km./hr. Long description, characteristics, performance. Les Ailes September 2, 1937, page 8, 2 illus., 2 tables.

France

Airplanes in Test. Very brief references only to tests in progress on the following: First issue—LeO-45 bomber (two Hispano-Suiza 14-AA supercharged engines of 1100 hp.), the prototype Amiot 370 racing airplane, Air-Couzinet 10, Bloch 300 "Pacifique" (three Gnôme-Rhône K-14 engines, speed 335 km./hr.), Farman 224 No. 2 (four Gnôme-Rhône K-14 engines), Farman 2200 transatlantic airplane (four Hispano-Suiza 12-X 690-hp. engines), and the Bleriot-5190 Santos Dumont seaplane.

Second issue—Bloch 131 No. 2 high-speed bomber (two Gnôme-Rhône engines), Morane-Saulnier M.S. 430 two-seater for training in piloting high-speed pursuits (two versions, one having a Gnôme-Rhône 9-Kfs engine developing 420-hp. at 1500 meters, and the other a Salmson 9-Ag. 395-hp. engine), Morane-Saulnier M.S. 405 No. 1 pursuit, and the bimotored Amiot 370 long-distance airplane.

Third issue—Lioré et Olivier LeO-45 bomber, Loire 70 seaplane for the high seas, Loire-Nieuport L.N.-20 three-place pursuit control plane (flying at more than 450 km./hr. with a total weight of 2250 kg., range 800 km. at 320 km./hr. cruising speed), L. N. 161 single-seater combat, Morane-Saulnier M.S.-430 two-place pursuit trainer (Salmson 9-Ag. 390-hp. engine), and another airplane of this type to be tested with a Gnôme-Rhône 9-Kfs developing 420 hp. at 1500 m. Les Ailes, August 26, September 2, and 16, 1937, pages 15, 15, 15.

A New Dewoitine. Thirty-seater Dewoitine 620 "Pacifique" for Air France has a top speed of 220 m.p.h. at 6000 ft. and payload of over 8000 lb. It is powered with three Gnôme-Rhône K.14s of 880 hp. each. Brief reference. Flight, July 1, 1937, page 32.

A New Leo Boat. Air France flying boat prototype, Liore et Olivier 24-6, (for Hispano-Suiza 12X 690-hp. engines) will carry 24 passengers. Total weight is 30,800 lb. and estimated top speed 210 m.p.h. Brief reference. Flight, September 30, 1937, page 338.

Nicolas-Claude NC-111 Tailless Slotted Canard Airplane. Proposed tailless slotted-wing airplane, and results of tests totaling 30 hours with the Aquilon. Les Ailes, September 9, 1937, page 13, 3 illus.

Technical Notes. Lignel 20, constructed for the Coup Deutsch, is powered by a Renault 220-hp. engine. Maximum speed is 400 km./hr. at 2000 meters and range 1225 km. Brief note. Les Ailes, September 2, 1937, page 8.

Technical Notes. The S.N.C.A. de l'Ouest has started construction on a novel Loire-Nieuport LN-10 12-ton combat seaplane having hull and floats, low wings, and a 26-meter wing span. It will be armed with machine guns and a cannon firing towards the rear. Powered by two 1400-hp engines it will have a range of 2000 km. Brief reference. Les Ailes, September 23, 1937, page 9.

Transatlantic Flying Boats. M. Victor. Cams 161 37-ton flying boat is designed to have a wing span of 40 meters and retractable floats, and to be powered by six Hispano-Suiza 12-cylinder 860-hp. engines each developing 1100 hp. at take-off. Estimated maximum speed is 360 km./hr. Details of this boat, designed but not under construction, are included in a description of results obtained by the English transatlantic experiments with the Caledonia. Details are also given of the Boeing 314 37-ton flying boat for Pan American Airways, and of the proposed 112-ton 150-passenger Glenn Martin. Les Ailes, August 26, 1937, page 8, 2 illus., 1 table.

Airplanes in Test. Amiot 150-Be explorer and bomber seaplane (two Gnôme-Rhône 14-Krsd 740-hp. engines, speed at total weight of 9400 kgs. 290 km./hr. at 2000 meters, and 286 km./hr. at 4000 meters, characteristic. given). Bréguet 462 Vultur bomber (two Gnôme-Rhône 14- No. 950-hp. engines, speed around 400 km./hr.). References to tests on these and private and commercial airplanes including the Lioré et Olivier LeO-246 seaplane (four Hispano-Suiza 12-Xirs 720-hp. engines, top speed 355 k./hr. at 2000 meters). Les Ailes, September 30, 1937, page 15.

Tests of the André Jacquemin Airplane Having a Vibrating Wing with Counterweights. G. Houard. Two-place light airplane in which the pilot acts as counterweight to the equilibrium of the wing. Long description and test results. Les Ailes, September 30, 1937, page 13, 3 illus.

Germany

Dessau's Giant. Junkers Ju.90 40-seater 250-m.p.h. airplane weighs 21 tons fully loaded. With the combination of split landing flap beneath center section and fuselage and underslung trailing flaps of the Junkers Double Wing, landing speed has been reduced to 62 m.p.h. Powered with four new Junkers Jumo 211 liquid-cooled gasoline engines (take-off power 1100 hp. each) the Ju.90 has a top speed of 250 m.p.h. The prototype has four 1000-hp. Daimler-Benz 600 gasoline engines. New fuselage shape and unusual form of balance for the elevator are pointed out in the photographs. Long description. Aeroplane, September 29, 1937, pages 391–393, 7 illus.

Shorter description. Flight, September 23, 1937, pages 302, 323, 2 illus.

Fiesler Fi-156 "Storch" Low-Speed Airplane. A. Frachet. Three-place touring airplane with folding wings and an Argus 240-hp. engine, lifts itself at less than 50 km./hr., lands in 30/40 meters in a wind of 3 meters per second and takes off in 14/19 meters. Maximum speed is 210 km./hr. Long description. Les Ailes, September 23, 1937, page 9, 3 illus.

The First Tests of the Junkers Ju-90. Monoplane of 35-meter wing span and 21 tons total weight with four Junkers 211 1100-hp. engines will transport 40 passengers over 2000 km. at a commercial speed of 360 km./hr. Few details and performance with four Mercédés-Benz M.B. 600 850/950-hp. engines. Les Ailes, September 30, 1937, page 4, 1 illus.

The Four Winds. Fieseler Storch monoplane, with the help of specially designed flaps and slots, has some Autogiro-like characteristics. It has been used at the German Army maneuvers for liaison duties. Landing run of 25 yards, take-off about 50 yards, and 24 to 130 m.p.h. speed range. Brief reference. Flight, October 14, 1937, page 377.

Heinkel He-116 Four-Motored Plane of 960 Hp. Flies at 330 Km./Hr. Airplane powered with four Hirth 508-B 240-hp. engines has a range of 4300 km. Characteristics and performance. Brief note. Les Ailes, September 30, 1937, page 8, 1 illus.

Steam-Driven Aeroplanes. New heavy bombers built by Henschel are said to be driven by steam turbines of 2500 hp. The machines are supposed to have a wing span of 115 ft., to be able to rise to a height of 42,000 ft., to cruise at 235 m.p.h., and to have a top speed of 280 m.p.h. References from "Steam Car Developments and Steam Aviation," and the "Daily Herald." Aeroplane, September 22, 1937, page 351.

Technical Notes. Heinkel has brought out a new four-motored airplane derived from its 111 and designed for North Atlantic postal service. Power is 960 hp., cruising speed 300 km./hr., and total weight 700 kg. Brief reference. Les Ailes, September 16, 1937, page 9.

Focke-Wulf 61 helicopter is powered by a Bremo Sh-144 160-hp. engine. Rotors turn in inverse directions and give the blades double articulation. A few more details. Les Ailes, September 23, 1937, pages 8–9.

GREAT BRITAIN

Aeroplanes at Hendon and Hatfield. Thirty-seven military and commercial airplanes taking part in the Royal Air Force Display and the Society of British Aircraft Constructors' exhibit. Few details and photograph of each. Table of characteristics and performance included. Aeroplane, June 30, 1937, pages 807–814, 37 illus., 1 table.

The Curtain Goes Up. Maia and Mercury components of the Mayo composite aircraft are described in detail and the differences between the Maia and a standard Empire boat are pointed out. Power plant, dimensions, weights, loadings, and performance are given for the Maia and Mercury both for individual flying and for composite flying as well as for the composite aircraft. Total available horsepower for take-off of the composite is 5120 hp. The Maia is powered by four Bristol Pegasus X engines and the Mercury by four Napier Rapier. Reasons for the conception of the composite aircraft are also discussed. Aeroplane, October 6, 1937, pages 418–420, 3 illus., 1 table.

Maia and Mercury are shown in a photograph as they were mounted together on the water. Flight, October 14, 1937, page 377, 1 illus. Aeroplane, October 20, 1937, pages 466, 467, 2 illus. (photographs only).

The Day. Until the pilots on the Mercury and Maia composite aircraft in turn have pulled their release levers the automatic release will not operate and then only if the lift of the upper component exceeds its weight by a certain predetermined amount. Brief reference in editorial. Flight, September 30, 1937, page 327.

Debutante Quartet. Gloster F. 5/34 single-seater multi-gun fighter (Bristol Mercury), DeHavilland Don advanced trainer (D.H. Gipsyking inverted vee-twelve, estimated top speed 223 m.p.h.), Miles advanced-trainer, general-purpose, fighter, bomber and reconnaissance monoplane (Rolls-Royce fully-supercharged Kestrel 690/750-hp. engine, speed about 295 m.p.h.), and the Blackburn fleet-fighter dive bomber (British Mercury). Few details and data on the trainers. Flight, July 1, 1937, pages 18a–18c, 12 illus.

Geodetic Performance. Performance figures on the Vickers Wellesley long-range bomber, torpedo carrier, or general-purpose machine (Bristol Pegasus PE-5.S.M.(a) engine delivering 900 hp. (max.) at 15,000 ft.). Range with normal load was 1325 miles at 187 m.p.h., and 2270 miles at 186 m.p.h. with overload. Armament, a few other details, and characteristics are given but unusual construction not mentioned. Editorial states that, fitted out with extra tanks, the Wellesley could fly nonstop for several thousand miles, possibly 8000. The British Air Ministry is urged to attack the long-distance record. Flight, July 8, 1937, pages 52 and 41–42.

"A New and Experimental." Airspeed Queen Wasp, a radio-controlled target airplane, DeHavilland Don advanced trainer, Phillips and Powis trainer, Airspeed Oxford advanced twin-engined trainer, Fairey P.4/34 bomber, Hawker Henley bomber, Gloster F.5/34 single-seater multi-gun fighter, Blackburn fleet fighter dive bomber, and the DeHavilland Albatross transatlantic transport. Few details of airplanes shown in the experimental park in connection with the Royal Air Force Display. Flight, July 1, 1937, pages 10–11, 1 illus.

Nomenclature. The Fairey light reconnaissance seaplane (Rapier VI motor) will be known as the Seafox I and the Blackburn dive-bomber fighter (Perseus motor) as the Skua I. Brief reference. Aeroplane, September 22, 1937, page 357.

The R.A.F.'s New Twin-Engined Trainer. Oxford, a military development of the Airspeed Envoy with redesigned nose, provides for general training in flying of larger types of aircraft, and in gunnery, bombing, photography, and other duties. Fitted with two Siddeley Cheetah X engines the airplane is capable of 195 m.p.h. Two-page cutaway drawing shows location of equipment, including bombs and Armstrong-Whitworth gun turret. Flight, July 1, 1937, pages 26, 27, 29, 2 illus.

The S.B.A.C. Display and Exhibition, 1937. Airplanes, armament, and engines exhibited at the Society of British Aircraft Constructors' Display. Few details of static exhibits and flying display. The Wellesley is said to do 226.5 m.p.h. at nearly 20,000 ft. Reference is made to performance of the Wellesley at the flying display. Mockup of an observer's gun fitted with Stieger parallel-motion sighting device is illustrated. Flight, July 1, 1937, pages 14–15, 18–22, 20 illus.

Three for Export. Hawker Hind for Jugoslavia (Rolls-Royce Kestrel XVI developing 690 hp. at 11,000 ft., speed about 200 m.p.h.), Gloster Gladiator (Mercury IX, 4 guns), and the Portuguese Hind (Kestrel V) bomber, fighter, or reconnaissance airplane. Photographs and only references to the planes. Flight, July 1, 1937, page 18d, 3 illus.

Sport and Touring Aircraft. Arpin cabin low-wing pusher monoplane with tricycle landing gear which is destined to be known as the "Safety-Pin." Long description.

Moss monoplane (cruising speed 120 m.p.h. on a 90-hp engine) is described in a second article. Aeroplane, September 22, 1937, pages 362–364, 369, 5 illus.

Hordern-Richmond airplane powered by two American Continental flat fours of 40 hp. Flying impressions. Aeroplane, September 29, 1937, page 401, 1 illus.

Night- and day-flying impressions of the v.p. Vega Gull which has a long range and cruising speed of 170 m.p.h. Flight, September 30, 1937, pages 328–329, 3 illus.

Wicke cabin monoplane powered with a 90-hp. Cirrus engine. Design and flying qualities. Flight, July 8, 1937, page 56, 2 illus., 1 table.

HOLLAND

Aviation in the Netherlands. P. Masefield. "Fokkers seem to be going all out for their cone-type rotatable gun turret." Armament, construction, performance for the following Fokker aircraft: T-4 twin-motored cantilever high-wing seaplane (two Bristol Pagasus III 735-hp. engines, top speed 158 m.p.h.) for bombing and torpedo dropping, made especially for the Netherlands East Indies; T-5 twin-motor cantilever midwing six-gun heavy battleplane, long-distance bomber or troop carrier (two Bristol Mercury VIII engines, top speed 248 m.p.h., range 746 miles with 2205-lb. load of bombs); C-11-W two-seater deep-sea reconnaissance braced biplane for catapult launching (Bristol Pegasus III 735-hp. engine, top speed 168 m. p.h.); D-21 single-seater low-wing monoplane fighter (830-hp. Bristol Mercury VII engine); and the G-1 attack monoplane. Reference is made to the T-5S-9, and T.8W twin-motor midwing monoplanes. Long article. Aeroplane, September 29, 1937, pages 394–397, 11 illus

The Four Winds. A long-distance monoplane, believed capable of over 250 m.p.h. and powered with three 850-hp. Wright Cyclone Gs, is being built for K.L.M. by the manufacturers of the Scheldemusch biplane. It is to be used in experimental transatlantic flights. Brief reference. Flight, September 30, 1937, page 330.

Holland Buys Bombers. Fokker T.5 twin-engined bombers are powered by two Bristol Pegasus XX fully-supercharged engines delivering 820 hp. at 2250 r.p.m. at 9000 ft. and a maximum power of 925 hp. at slightly higher altitudes. Alternative power plants are Gnôme Rhône 14 NO-OIs. Maximum speed is 242 m.p.h., range 870 miles. Armament and other details of first of 16 heavy bombers being tested for the Dutch air force. Flight, October 14, 1937, page 380a, 3 illus.

ITALY

Building Up Prestige. Sixteen assorted records gained by Italian airplanes in the past eight months. List of planes, engines, and records made. Aeroplane, September 22, 1937, page 350.

Italian Aircraft Participating in the Istres-Damascus-Paris Race. The three winning Savoia-Marchetti S-79 racing airplanes derived from bombers (three Alfa Romeo 126 RC-34) have a maximum speed of 450 km./hr. at 4000 meters and cruise at 400 km./hr. The two Fiat B.R.20 all-metal bombers (two Fiat A-80 RC-41 1000-hp. double-row radials) have a top speed of 440 km./hr. and range of 2500 km. The two mysterious Caproni 405 "Procellaria" bombers (two Isotta-Fraschini Asso XI RC.40 liquid-cooled 850-hp. engines) fly at 420 km./hr. at 5000 meters and have a range of 2500 km. and ceiling of 7000 meters. The two Caproni's did not take off. Details of the three types and photographs of a S-79s and a Fiat BR-20. Les Ailes, September 2, 1937, page 5, 2 illus.

The Savoia-Marchetti S-79 winner of the Damascus Race is not a military airplane but a racing airplane built for the London-Melbourne race in 1934. The Savoia-Marchetti S-81 bomber which has a speed of 90 km./hr. less than the S-79 was designed as a military airplane. Brief note on the Race results. Les Ailes, September 16, 1937, page 11.

JAPAN

Technical Notes. Japanese low-wing long-distance monoplane of 28 meters span has retractable landing gear and tail wheel and will be powered by a 800-hp. Kawasaki engine cooled by ethyl glycol. Weight empty is 3300 kg. and 7000 liters of gasoline are contained in 14 wing tanks. Range is 16,000 km. Brief reference. Les Ailes, August 26, 1937, page 9.

U. S. A.

Curtiss Hawk 75. Pursuit airplane just released for export has been developed from the Y1P-36 of which 230 have been ordered recently by the U.S. Army Air Corps. At a cruising speed of 240 m.p.h., range is 1380 miles at 16,400 ft. (1540 miles at 210 m.p.h. cruising speed). Normal gross weight is 5305 lb. but the airplane can take off, fly and maneuver with full military load plus full gas tanks at a gross weight of 1160 lb. above normal. Airplane is powered by a Wright Cyclone SGR-1820G-3 engine developing 840 hp. at 2100 r.p.m. at 10,700 ft. Description including armament, specifications, performance. Aviation, October, 1937, page 43, 2 illus., 2 tables.

The Four Winds. It is believed the projected Sikorsky double-decker flying boat will be powered by six double-row 1500-hp. Wright Cyclones. Brief reference. Flight, September 30, 1937, page 330.

The Rising Generation. "The technical departments of every Air Force in the world would give a lot to have 48 hrs. alone with this machine"—the Bell XFM-1 fighter for the U.S. Army Air Corps. "The XFM-1 should do over 350 m.p.h. which would make it more than 100 m.p.h. faster than the American Boeing YB-17 bombers of the type it is meant to deal with." Description and photograph showing rear view. Aeroplane, September 22, 1937, page 364, 1 illus.

Roman Holiday. New Seversky two-seater fighter developed for the export market. Two views, one showing installation of the free Browning gun, are included in an account of the National Air Races at Cleveland. Flight, September 23, 1937, pages 314b–314c, 8 illus.

Sever-Sky Convoy Fighter. Convoy fighter, released for export, may be used also as a basic trainer, advanced trainer, observation plane, attack plane or fast light bomber. It can be equipped with any Wright or Pratt and Whitney engine from 400 to 1200 hp., guns up to seven, and two bomb racks capable of carrying 300-lb. bombs. Powered with a 1000-hp. Cyclone it has a top speed around 300 m.p.h. Few details. U.S. Air Services, October, 1937, page 36, 1 illus.

Sport and Touring Aircraft. Aeronca K 1938 model. New features. Brief. Western Flying, October, 1937, page 28, 1 illus.

Babcock two-place midwing monoplane powered with a Rover engine has a top speed of 100.9 m.p.h. Specifications. Aviation, October, 1937, page 46, 1 illus.

Gwinn "Aircar" two-place cabin biplane with tricycle-type landing gear and automobile-type controls. Long description. Aero Digest, October, 1937, pages 56, 58, 6 illus. Aviation, October, 1937, pages 36–37, 5 illus.

Rearwin Speedster when powered with a Menasco C4S 150-hp. has a top speed of 163 m.p.h. and cruising range of 550 miles. Short description, specifications. Western Flying, October, 1937, page 30. Aviation, October, 1937, page 46, 1 illus.

Sundorph cabin monoplane, powered with a 285-hp. Jacobs engine, was flown in the Bendix race at an average speed of 166.21 m.p.h. Description. Aviation, October, 1937, page 45, 3 illus.

Waco "N" Series Biplane four-place cabin has a new three-wheel landing gear. Description but no specifications or performance. Aero Digest, October, 1937, page 54, 2 illus. Aviation, October, 1937, page 40, 2 illus. Western Flying, October, 1937, pages 26–27, 1 illus.

Half-Pint Racers. R. C. Morrison. Design and construction of the airplanes, home-built and otherwise, which took part in the National Air Races at Cleveland. Flight, October 7, 1937, pages 356a–356d, 9 illus.

U. S. S. R.

Innoc-Ant Abroad. Russian 12-seater ANT-35 bimotored airplane. Photograph only. Letter on another page states it has a cruising speed of 190 m.p.h. Aeroplane, October 6, 1937, pages 426, 434, 1 illus.

The Record of Rossi of 311 Km./Hr. Over 5000 Km. Has Been Beaten in Russia. T.K.B.-26 bomber (two M-85 800-hp. engines) has won two records for carrying at 325 km./hr. a load of 1000 kg. The flight was carried out between Moscow-Sebastopol-Sverdlovok at an altitude higher than 4000 meters. Brief note. Les Ailes, September 16, 1937, page 3.

Manually-Operated Aircraft

Cycle Airplane with Flapping Wings Is Under Construction at Seyne-sur-mer. Tchérémissinoff, Hollande, Vassal are building a manually-propelled biplane with flapping wings under German patents. Description of design, especially wing structure. This article is followed by brief references to results obtained by Hoffmann, E. Casso, and Daudot and Duneau with manually-operated or cycle airplanes. Les Ailes, September 16, 1937, page 13, 4 illus.

Aircraft Maintenance

Maintenance Procedure at TWA's Overhaul Bases. Major overhaul operations performed on TWA aircraft after every 100 flying hours, minor procedures carried out after 25 flying hours, or at any time a plane lays over at an outside field, and operations at 50 flying hours. Detailed descriptions of these operations which are now carried out at Newark, Chicago, and Los Angeles instead of being concentrated at Kansas City. Aero Digest, October, 1937, pages 31, 101, 1 illus.

Air Transportation

On Air Transport from the Passenger's Point of View. C. G. Grey. "I still believe flying is dangerous, and so shall continue to agitate in favour of safer flying. . . ." Points to interest aircraft constructors, airline operators, and pilots from the author's experience in flying on airlines of Europe. First issue—Sea flying in land machines, law of averages, aircraft design, blind flying, German caution, and pilots' tricks of technique not calculated to make passengers feel more comfortable.

Second issue—Use of engines to help in landing, collision risks, what should be done towards detectors, and fire risks. Aeroplane, September 22 and 29, 1937, pages 353–355 and 385–386.

Transatlantic Experiment. H. A. Taylor. Navigational preparations, radio equipment, and problems behind the Caledonia's notable Atlantic test flight. Experiments of the United States, Germany, and France are briefly referred to. Flight, July 8, 1937, pages 45–46, 10 illus.

The North Atlantic Season. Flights made by Pan American and Imperial Airways, flying time, and average speeds are listed. All commanders commented on the accuracy with which winds and weather were forecast and there seems to have been a gradual improvement in use of winds at different heights as experiments went on. Aeroplane, October 6, 1937, page 426, 1 table.

On Criminals of the Clouds. C. G. Grey. Need for control of British air traffic in the clouds. In Germany all military flying is put under control of the air traffic officers when visibility is bad. Aeroplane, October 6, 1937, pages 411–412, 1 illus.

Airships

Air and Water. Dirigibles are shortly to be put into regular service on a number of commercial air routes in U. S. S. R. The V6 dirigible is reported to have flown for 130 hours without refueling and breaking the record set by the Graf Zeppelin in 1935. Brief reference. Engineer, October 15, 1937, page 419.

The Four Winds. Record duration flight without refueling is claimed for the Russian V6 semi-rigid airship. Previous record of 119 hours, set by the Graf Zeppelin in 1935, was bettered by 11 hours. Brief reference. Flight, October 7, 1937, page 353.

The Loss of the "Hindenburg." Complete report of the U.S. Bureau of Commerce Committee which investigated the accident. Aircraft Engg., October, 1937, pages 261–267.

A New Argument for Airships. There are on the drawing boards designs of an airship of 10,000,000 cu. ft. capacity which would carry aloft nine bombing planes of about 10,000 lb. each. The airship would be classed as an aircraft carrier, would cruise at 60 or 70 m.p.h. and have a range of 15,000 miles. Brief note. Scientific American, October, 1937, page 245.

Balloons

The Balloon Barrage. Damage to ten balloons of the Royal Air Force experimental kite-balloon barrage during two thunderstorms at Cardington. Considerable progress has been made in the barrage and as many as 20 balloons at a time have been seen over Cardington.

Further information on the peculiar behavior of sundry balloons at Cardington lately. A French balloon under test, which had a ceiling of about 20,000 ft., escaped and eleven balloons were destroyed by lightning. Brief notes. Aeroplane, September 22 and 29, 1937, pages 357 and 389, 2 illus.

Propellers

Constant-Speed Airscrews. V.D.M. constant-speed propeller to be built in England is electrically controlled by a motor remote from the propeller actuating the pitch-changing mechanism through a flexible shaft. Few details. Flight, September 30, 1937, page 338.

Practical Airscrew Performance Calculations. F. M. Thomas, F. W. Caldwell, and T. B. Rhines. Whole body of test data is coordinated in a form suitable for use in performance calculations, and particular reliance is placed on large-scale wind-tunnel results. Analysis permits quick estimates to be made, the degree of accuracy obtained being a function of the amount of time available to the calculator. It is especially adapted to performance calculations for aluminum-alloy variable-pitch propellers. Data still required on certain subjects are specifically designated and suggestions are made for carrying out research. Test data were obtained by United Aircraft and Transport Corporation, N.A.C.A., DeHavilland Aircraft Company (Airscrew Division), and the British Aeronautical Research Committee. Data from flight tests and static whirl tests were used in checking and filling in blank spaces. Royal Aeronautical Soc., Preprint for Meeting, October 21, 1937, 71 pages, 34 illus., many tables and equations.

The Four Winds. Official approval has been given for the use of Rotol propellers with four models in the Bristol-Mercury range, the Pegasus X, and the Rolls-Royce Kestrel. Tests on a Rotol model designed for the Merlin are under way. Brief reference. Flight, September 23, 1937, page 307.

On Metal Airscrews. Propeller blade vibration and B.C. Carter's device for measuring vibration on propellers. Brief review of paper presented before the Royal Aeronautical Society. Everel single-blade automatic controllable-pitch wooden propeller is illustrated. Aeroplane, September 22, 1937, page 365, 3 illus.

Wooden Blades for C.P. Airscrews. Schwarz controllable-pitch wooden-bladed propellers. Method of forming the blade is described. Drawings illustrate how the compressed wood root screws into the steel sleeve and show two typical arrangements for fixing the root of a blade into the hub of the controllable-pitch propeller. Aeroplane, September 22, 1937, page 374, 2 illus.

Records and Races

Height Record Home Again. Record flight to 53,937 ft. made by Flt. Lt. M. J. Adam on June 30 in a Bristol 138 (Pegasus special engine). Few details. One photograph shows emergency instructions for rescuing the pilot printed on the outside of the fuselage. Flight, July 8, 1937, pages 52a–52b, 4 illus.

Technical Notes. A Russian military airplane was flown between Moscow and Kharkov at 8000 meters altitude. Outside temperature was −30°. Brief reference to this flight, to a test flight of the Lockheed Electra stratospheric airplane with a pressure cabin, and to the pressure cabin of the Boeing 307 for Pan American Airways. Les Ailes, September 23, 1937, page 9.

The Way of the Winner. C. Gardner. Winner of the King's Cup Race for the second year in succession explains the navigational and control methods which brought his Percival Mew Gull home at 233.7 m.p.h. average speed. Flight, September 23, 1937, pages 304–306, 5 illus.

National Air Races

Cydelites on the Cleveland Air Races. Account of the National Air Races in the usual Cy Caldwell style. Exhibition of the Army's "Three Skylarks" from Maxwell Field is considered the best stunt of the show. Aero Digest, October, 1937, pages 28–30, 100, 11 illus., 1 table.

Race Round-Up. Speeds attained in the 1937 National Air Races compared with those of the previous Races, types of engines powering the competing airplanes, equipment and material in Rudy Kling's winning plane for the Thompson Trophy, the two Wittmann racers, and meeting of the Institute of the Aeronautical Sciences on "Engineering for Speed." Aviation, October, 1937, pages 24–25, 76, 78, and 55–56, 9 illus.

Accounts of events. Western Flying, October, 1937, pages 11–14, 6 illus., 2 tables. U.S. Air Services, October, 1937, pages 11–14, 5 illus., 1 table.

The Russian Claim to Records. Further discussion disputing the F.A.I. acceptance of the Russian record-breaking flight over the North Pole, July 13 to 15. Aeroplane, October 13, 1937, pages 436–437.

Aircraft Instruments and Navigation

Aperiodic Compass. Kollsman 154 aperiodic compass is designed for high-speed long-range aircraft and is provided with independent illumination for compass scale and bowl. Short description. Aviation, October, 1937, page 53, 1 illus.

Multi-Chron. Watch, timer, chronograph, and tachometer designed to translate time into speed and speed into time. Short description. Aviation, October, 1937, page 52, 1 illus.

Pneumatic Telemetering. C. B. Moore. System for remote transmission of flow-rate readings by pneumatic means, and how this method can be adapted to telemetering pressure and temperatures. Instruments, September, 1937, pages 242–243, 248, 3 illus.

"Landing-Sticks." Wing Commander Noake's invention of a hanging stick not only gave the pilot warning but operated the elevator control so the machine would flatten out. Device was tested at the Royal Aircraft Establishment. Brief editorial suggests use of such a device for flying boats and refers to the Noake device as well as to the Pemberton instrument designed to tell the pilot when he is at some predetermined height above the sea. Flight, October 7, 1937, pages 343–344.

Navigation

Running Fix. Another method of plotting one's track from the three bearings taken on a single object, whether by bearing compass or D/F, at known time intervals. Flight, July 1, 1937, page 38.

Simplifying Astronomical Navigation. Points of the new British "Air Almanac" described with examples and comparisons. Flight, September 30, 1937, page 336, 1 table.

Airport and Equipments

An Airport Plan. J. W. Wood. Characteristics of the Wood system which provides separate runways for simultaneous take-offs and landings. Detailed description. Aviation, October, 1937, pages 26–27, 74–75, 10 illus.

Concrete for Airport Runways, Aprons, Taxi Strips and Pavements. A. A. Anderson. Transverse joints, crown, and surface finish are discussed. Five airport runways are illustrated, among them Vandalia. Aero Digest, October, 1937, pages 25–26, 5 illus.

Concrete Apron Preparation. Sisalkraft specially waterproofed fabric of great strength is laid over the ground and concrete placed over it. This method has been used for twenty R.A.F. airports. Brief note on the fabric. Flight, July 1, 1937, pages 24–25.

Landing at Sea. Scheme for landing autogiros on ships has been patented by R. A. C. Brie of the Cierva Autogiro Company. A platform is swung over the side of the ship to be used in still air. Drawings. Aeroplane, September 29, 1937, page 404, 2 illus.

Safe Anchorage. "Scrulix" anchor, a novel type of screw picket supplied to the Air Ministry, Admiralty, and War Office, is used for picketing aircraft, anchoring temporary hangars, and many other purposes. Few details. Flight, September 23, 1937, page 312, 1 illus.

Miscellaneous Equipment

Aeronautics in Gargantua. Aeronautical equipment on view at the Engineering and Marine Exhibition at Olympia. Brief review. Aeroplane, September 22, 1937, page 373.

Air and Water. Lap straps for seats on passenger planes, artificial horizon, and directional gyroscope, as well as oxygen apparatus for airplanes flying at altitudes of more than 15,000 ft., are required by the new British regulations. Brief reference. Engineer, October 1, 1937, page 365, Aeroplane, October 6, 1937, page 409.

Here and There. Equipment exhibits at the Society of British Aircraft Constructors' Display are illustrated. New 30-gallon Bromylene "Fire Froth" type B extinguishers used at every R.A.F. station at home and abroad are referred to. Flight, July 1, 1937, pages 23–25, 16 illus.

Aeronautical equipment displayed is discussed. Photographs given in another section. Aeroplane, June 30, 1937, pages 799–806, 10 illus., and pages 821–824, many illus.

Parachutes

The Four Winds. "One of France's new 300-m.p.h. Norane fighters is being adapted for experiments with release of parachutes at high speeds. A good deal remains to be learned about the behavior of 'brollies' under these conditions. Brief reference. Flight, September 23, 1937, page 307.

Metals

Heat Treat. E. R. Smith. Heat treating equipment and methods employed by Lockheed Aircraft Corporation including salt bath used, treating duralumin, steel annealing, treating stainless steels, normalizing parts, and carborizing. Western Flying, October, 1937, pages 15–17, 24, 5 illus.

Plastics

An Aircraft Plastic. Tufnol synthetic nonmetallic material is only half the weight of aluminum and is supplied in sheets, tubes, rods, bars, angles, and channels. One special brand is made for use at temperatures up to 392°F. Brief note on properties of this material. Aeroplane, September 22, 1937, page 374.

For Screens and Windows. V.7 Aviation Rhodoid, a new transparent sheeting for aircraft windows, will remain stable in quality up to highest temperatures likely to be used in molding or bending. Very few details. Flight, September 23, 1937, page 312.

More Synthesis. Aero Research, Ltd., are turning out 20-ft. lengths of plastic material having an elastic modulus of 7.4×10^6 lb./sq.in. Tensile strength is 45,000 lb./sq.in., and specific gravity 1.34. Brief reference. Aeroplane, September 29, 1937, page 392.

Rubber

Rubber in Airships. Rubber used in the construction of the new flying boats of Imperial Airways. From Rubber Growers' Association Bulletin. India Rubber World, October 1, 1937, page 71.

Power Plants

Engine with Free Piston. L. Keuleyan. Gas turbine and an internal-combustion engine to supply it with gas are proposed for furnishing the power for aircraft. The 2400-hp. marine engine designed by E. Capitaine in 1897 is described. This engine had free opposed pistons returned by crankcase pressure, and two cylinders of 1-meter bore and 4-meter stroke. Deutz gas engine (1905), Barber gas turbine (1791), Matricardi air compressor (1910), and the Junkers compressor (1918) are also discussed in this issue.

The second issue describes a design by M. Brutzkus. By burning fuel excessively in an ordinary engine and by expanding the gas products in a turbine, he hopes to produce 250 hp. per cylinder liter. The author considers the final solution to be a steam-gas generator which will utilize exhaust gases at high pressure and the superheated steam. Two-cycle double-acting engine with a free piston, constructed by F. Mélot in 1922, and the Pescara engine are also described. Les Ailes, August 26 and September 9, 1937, page 7, 7 illus.

Rockets. A. Ananoff. Experiments in rocket propulsion carried on by Oberth, Winckler, Tiling, and Zucker in Germany, and by the American Rocket Society, the Cleveland Rocket Society, and Professor Goddard in America. To be continued. Les Ailes, September 2, 1937, page 9, 4 illus.

Technical Notes. A 1000-hp. steam powerplant for aircraft, proposed by Broobeck in a previous article, is discussed by P. Persyn. Brief note on efficiency obtainable. Les Ailes, August 26, 1937, page 9.

The Béchard Steam Engine. M. Victor. A rotating oil-burning boiler of extremely simple design and having excellent thermal properties is designed to supply steam to a fixed turbine wheel. Its operation would be automatic and absolutely silent and power would not decrease with altitude. Long description and possible application to aviation. Les Ailes, Sept. 30, 1937, pages 7–8, 4 illus.

Engine Design and Research

Cooling of a Radial Engine in Flight. O. W. Schey and B. Pinkel. N.A.C.A. flight tests to determine effect of indicated horsepower and mass flow of cooling air on cylinder temperatures. Results are correlated with those of laboratory tests on single-cylinder blower-cooled test engines. Novel method for independently varying velocity of cooling air and cylinder horsepower of the engine in flight tests is described. Tests were made on a Grumman Scout XSF-2 airplane equipped with a Pratt & Whitney 1535-72 14-cylinder 2-row radial engine. Journal Aeronautical Sciences, September, 1937, pages 448–452, 9 illus., 1 table, 7 equations.

Exhaust Valves. C. G. Williams. Researches of the Institute of Automobile Engineers showing the importance of the various factors controlling exhaust-valve temperature. Short abstract of paper reviewing results obtained. Automobile Engineer, July, 1937, page 273, 1 illus.

Aircraft Powerplant Trends. G. J. Mead. See TECHNICAL DATA DIGEST, June 1, for abstract of preprint. S.A.E. Jour. (Trans.) October, 1937, pages 455–467, 22 illus.

The Behaviour of Oil Coolers. M. A. A. Allfrey. Design of honeycomb oil coolers for aircraft engines for maximum cooling efficiency combined with minimum drag and minimum danger of freezing up. Theory and experimental data include: Behavior of single cooling passage; relationship between pressure and flow in idealized cooler element; application of theory to coolers with bypass valves, but without heating jackets, and to coolers without heating jackets but with air control; purpose of jacket; spread of flow from warmer passages to chilled line; and spread of flow across a group of oil cooling passages in parallel. Marston honeycomb oil cooler for the R.A.E. illustrated. Aircraft Engineering, October, 1937, pages 257–260, 7 illus., 12 equations.

Features of the In-Line Air-Cooled Aircraft Engine. A. T. Gregory. Paper, and discussion entitled "Contends Jacketing Developments Also Apply to Radials," by N. N. Tilley is included. (See TECHNICAL DATA DIGEST May 15, for abstract of preprint.) S.A.E. Jour. (Trans.), October, 1937, pages 473–482, 13 illus., 2 tables.

Injection v. Carburation. A. Mandrel. Advantages of the fuel-injection engine for aviation. Pulsating phenomena in the fuel system, and nature of the fuel should be considered and a method of test developed to ascertain combustion rate of complete fuel. Very brief abstract from Journal de la Société des Ingénieurs de l'Automobile. Automobile Engineer, September, 1937, page 347.

Making Shrink Fits by Cooling in Liquid Nitrogen. Fixture for applying aluminum cylinder heads of radial aircraft engines to their steel cylinders, and method are described. Abstract, Revue de l'Aluminium, July and August. Automotive Industries, October 23, 1937, page 619, 1 illus.

Engines

Abroad. "Premier Mussolini has put the fire under the Italian aircraft industry to get out and design some engines on its own hook." Alfa Romeo is building Bristol, de Havilland and Armstrong-Siddeley motors, Isotta Fraschini the Lorraine, Hispano-Suiza and Gnôme-Rhône engines, Piaggio Gnôme-Rhône and Bristols, and Fiat is working full out on Pratt & Whitneys. Brief reference. Aviation, October, 1937, page 65.

Engines. Engines exhibited at the Society of British Aircraft Constructors' Display. Few details of the Alvis Pelides, and Alcides, Armstrong-Siddeley Tiger VIII, Bristol Pegasus XVIII, Perseus, and Hercules, Gipsy Six Major II, Napier E.108, and Rolls Royce Kestrel XVI engines. Drawings show hub for the new Fairey variable-pitch propeller, and the Alvis Pelides Major (1000–1500 hp.) with covering over a part. Flight, July 1, 1937, pages 15, 18, 7 illus.

The Four Winds. "There is a rumor that the French Government will acquire a large number of Pratt and Whitney two-row radials, supposedly of the Twin Wasp type. This step would be somewhat drastic, for the American Government never released an engine for export until its own Army and Navy are in possession of something very much better. Incidentally, the production if Hispano-Suiza liquid-cooled engines is said to be extremely small." Brief reference. Flight, September 23, 1937, page 307.

Liquid Cooling Today. At high speeds the ducted, or tunnel, radiator applied to the new Merlin-powered fighters and bombers may actually contribute to, instead of detracting from, the propulsive force. Drag may be reduced to zero at 300 m.p.h. The scheme may be further developed by the introduction of energy of the exhaust gases in a suitable duct system, and it is said that zero drag would then be attained at 140 m.p.h. Rolls Royce latest cowling and cooling systems are also described in a general discussion of liquid-cooling of aircraft engines. Photographs of airplanes show the new Bell multi-seater; Hispano-Suiza cannon engine in the Dewoitine D.500 fighter bought by the British Air Ministry; exhaust-driven superchargers on the glycol-cooled Curtis Conqueror engines of the U. S. Army Air Corps Consolidated two-seater pursuit; advanced Kestrel XVI installed in the new Miles trainer/general-purpose military airplane; and Rolls Royce installation on the Heinkel He 70-a monoplane. Flight, September 30, 1937, pages 338a–338d, 339, 6 illus.

Official Powers. Sleeve-valve design of the Bristol Hercules, Perseus, and Aquila, photograph only of the Rolls-Royce Merlin, and a very few details and photographs of the Bristol Perseus, Mercury XI and XII, Pegasus XVIII, Armstrong-Siddeley Tiger VIII, Pobjoy Niagara, Armstrong-Siddeley Cheetah, DeHavilland Gipsy Six and Gipsy Major and Cirrus Minor engines. Table of specifications and performance included. Aeroplane, June 30, 1937, pages 815–819, 17 illus, 1 table.

Ranger. Twelve-cylinder inverted-vee geared supercharged aircraft engine. Drawings. Automotive Industries, October 9, 1937, pages 495–596, 3 illus.

A Sharper Dagger. Napier Dagger E.108 fully-supercharged 24-cylinder engine has finning of closer pitch than earlier models, is fitted with a double-entry blower, and is arranged to drive a variable-pitch propeller. Photograph only. Flight, July 8, 1937, page 64, 1 illus.

Super Buccaneer. Menasco Model C6S-4 aircooled six-cylinder inline engine which powered Rudy Kling's Folkerts Speed King winning airplane at the National Air Races. Engine develops 250 hp. at 2350 r.p.m. at 5000 ft. altitude with 290 hp. at 2400 r.p.m. permissible for take-off at sea level. Long description. Aviation, October, 1937, pages 42, 78, 2 illus.

A Swash-Plate Engine Design. Wooler radial aircraft engine operating on the swash-plate principle and having horizontally opposed cylinders. Layout drawing and advantages of the design, but no details. Flight, September 23, 1937, page 312, 2 illus.

Vee-Twelve Par Excellence. Cylinder heads and blocks cast in a unit are new features of the Rolls-Royce Merlin II which is similar in design to the Kestrel rather than the Merlin I. Maximum power of the Merlin II is 1030 hp. at 3000 r.p.m. at 16,250 ft., and that of the Merlin I 1025 hp. at the same r.p.m. and altitude. Both are fully supercharged, ethylene-glycol cooled and have 12 cylinders in two monoblocs of six set at a 60-degree vee. Special turbulent combustion chambers in a detachable head are a feature of the Merlin I. Long description of design and performance, and many drawings and photographs. Cooling systems and details of mounting are shown on drawing. Flight, September 23, 1937, pages 308–310, 8 illus., 1 table.

PARTS AND ACCESSORIES

The Cross Rotary Valve. Rotary valves with controlled loading adapted to suit inline, vee, and radial engines. Long description and reference to the Cross linerless aluminum cylinder and light alloy piston fitted with glass hard rings. Automobile Engr., July, 1937, pages 271–272, 4 illus.

Multi-Stage Boost Controls. E. W. Knott. Variable datum boost control, boost override for take-off, three-phase boost controls, throttle lever action, and the Hobson master control carburetor incorporating three-phase boost control, two-stage automatic mixture control, and all necessary linkage. Twin-engine cockpit control for this carburetor also discussed. Long description. Flight, Aircraft Engr. Sup., September 30, 1937, pages 16–18, 6 illus.

To Be Made in England. Bronzavia flame damper for radial and inline engines releases gases in long, narrow, vertical ribbons projected vertically across the slipstream, and is of value in making airplanes less easily visible from the ground. A Bronzavia carburetor with automatic altitude compensator and automatic boost control, an engine speed synchronizer, and oxygen distribution apparatus, also being made by Avimo under license in England, are referred to. Brief. Flight, September 30, 1937, page 331, 3 illus.

Aero Motors at Milan. Alfa Romeo experimental 135 R.C. 33 1500 hp. (18 Pegasus-like cylinders in two rows). Fiat As 6 (two 12-cylinder Fiat engines back-to-back driving oppositely-revolving propellers on a common shaft and developing 3100 hp. for weight of 2050 lb.) and the A.80 18-cylinder radial (1100 hp., 45.72 liters capacity). Isotta Fraschini Asso 120 IRCC 40 12-cylinder inverted vee (675 hp. at sea level, 778 hp. for take-off, 26.68 liters, weight dry 1190 lb.), the Asso XI RC 40 12-cylinder upright vee liquid-cooled (836 hp. at rated height for 1130 lb. dry weight, 32.65 liters), the Asso L 121 RC 40 12-cylinder inline (900-hp. at rated height, weight 1290 lb.), the Astro 140 RC 35 twin-row 14-cylinder radial (820 hp., dry weight 1180 lb., 34.69 liters), and other lower-powered engines.

Piaggio P VII c.16 (single-speed supercharger, 460 hp., weight 716 lb., 19.34 liters), P VII C.45 (two-speed supercharger, 450 hp., same capacity), P XI RC.40 (1000 hp., 38.6 liters), P XII RC.40 (1600 hp., 56.9 liters, weight 1760 lb.), P XR (Stella) 9-cylinder (700 hp., 948 lb., 24.858 liters).

Junkers Jumo 211 (1.55:1 reduction, maximum permissible at 1700 meters 1025 hp. at 2300 r.p.m., highest cruising 925 hp. at 2300 r.p.m. at 4200 meters), also the Jumo 210. Argus, Bramo, Gnôme Rhône, Hirth, Hispano-Suiza, other Junkers, and Walter engines are referred to. Few details of each. Aeroplane, October 13, 1937, pages 456–457, 3 illus.

Cirrus Minor Considerations. Installation details and drawing. Aeroplane, October 6, 1937, pages 421–422, 3 illus., many drawings.

Engines at Milan. Fiat A.80 R.C.41 (1000 hp. at 2100 r.p.m. at 13,450 ft. and 1030 hp. for take-off), and the A.80 R.C.20, both geared and supercharged 18-cylinder radial engines, and the A.74 R.C.38 14-cylinder (840 hp. at 2400 r.p.m. at 12,500 ft.). Piaggio P. XII R.C.40 18-cylinder (1600 hp.) and P. XI R.C.40 (1000 hp.). Isotta Fraschini Astro 140 R.C.35 14-cylinder radial (820 hp. at rated altitude). Gnôme Rhône M.14 two-row small-diameter (680 hp. at 13,100 ft.), and P.18 (1600 hp. at 2300 r.p.m. at 14,700 ft.).

Argus As.10 C. inverted (240 hp. maximum). Walter Sagitta II R.C. fully supercharged "canon" engine (520 hp. at 13,450 ft.). Bramo 323-J Fafnir 9-cylinder radial, powering the Dornier Do.19 experimental bomber and supercharged for operation at 13,780 ft. Few details and table giving characteristics and horsepower of 54 engines. Flight, October 14, 1937, pages 381–382, 4 illus., 1 table.

The Labors of Hercules. A few particulars of the medium-supercharged Hercules 14-cylinder sleeve-valve two-row radial engine (maximum output 1375 b.hp. at 4000 ft.), as well as of the Northrop airplane specially built for the Bristol Company as a flying test bed and estimated to do about 295 m.p.h. with the Hercules. During official type tests the 595-hp. Bristol Perseus III-M sleeve-valve engine achieved a fuel consumption of 0.43 lb./hp.-hr. Short discussion. Aeroplane, October 6, 1937, page 422, 1 illus.

Mechanical Specifications of the 1938 American Passenger Cars. Tables of engine parts and other specifications. Articles on new designs. Automotive Industries, October 23, 1937, pages 556–572, 600–605, 13 tables.

Mercedes DB-600—the First German 1000-Hp. Aircraft Engine. W. Zuerl. DB-600 A/B 12-cylinder liquid-cooled gasoline engine with ground supercharging (1000 hp. at 2400 r.p.m. for five minutes, and 800 hp. at 2200 r.p.m. continuously, weight dry 545 kg.), and the DB-600 C/D (950 hp. at 2300 r.p.m. for one minute, and 800 hp. at 2200 r.p.m. at 4000 meters, weight dry 555 kg.). Construction described with specifications and performance. A.T.Z., September 10, 1937, page 441, 2 illus., 1 table.

Prague Aero Show. Characteristics and performance of 29 Czechoslovakian aircooled engines are given in a table and some of the designs discussed. A.T.Z., August 10, 1937, pages 394–397, 2 illus., 1 table.

The Tiger VIII Engine. Photographs showing the camdrum with train of satelite gears and oil pump, cylinder heads, induction elbow and auxiliary drive casing, and assembly of master and six auxiliary connecting rods. Aircraft Engg., October, 1937, page 276, 4 illus.

Trend of Air-Cooled Aero Engines—The Next Five Years. A. H. R. Fedden. See TECHNICAL DATA DIGEST, May 15, for abstract of preprint. S.A.E. Jour (Trans.), October, 1937, pages 437–454, 467, 25 illus.

Short discussion of this paper and newer data on the Walter Sagitta 12-cylinder inverted-vee engine given by T. Kumpera with Mr. Fedden's reply. Jour. Royal Aeronautical Soc., October, 1937, pages 973–974.

Engine Testing Equipment

On the Art of Dynamometry with Particular Reference to the Measurement of Engine Power in Flight. N. S. Muir. New transmission dynamometer developed primarily for use in aircraft, and results already obtained in flight at the Royal Aircraft Establishment. The author describes steps in development of this dynamometer in detail, discusses flight test results, and considers how the apparatus can be employed on new engines and with variable-pitch propellers.

Part I of the article (29 pages) reviews development of dynamometers in the past 180 years. Part II (3 pages) refers to the problem of variation of engine power with height and gives notes on a few attempts at solution by direct measurement. Jour. Royal Aeronautical Soc., October, 1937, pages 864–915, and (disc.) 915–920, 65 illus., 2 tables, 7 equations.

Scientific Silencing. Aircraft-engine and propeller test tunnel produced by Burgess Products Co., acoustical engineers, in collaboration with Armstrong Siddeley Motors, Ltd. Two are in operation and a third has been put up at the R.A.F. station at Henlow. Very few details. Aeroplane, October 13, 1937, page 463.

Fuels and Lubricants

Collected Results on Viscosity of Lubricants Under Pressure. I. Fatty Oils. M. D. Hersey and R. F. Hopkins. Principal results of experiments are reduced to the same units and collected for comparison. Viscosity-pressure-temperature data are given for eleven different oils. Jour. Applied Physics, August, 1937, pages 560–566, 1 illus., 14 tables.

Engine and Laboratory Tests of Stability of Aviation Oils. O. C. Bridgman and E. W. Aldrich. See TECHNICAL DATA DIGEST, May 15, for abstract of preprint. S.A.E. Jour. (Trans.), October, 1937, pages 483–492, 15 illus., 4 tables.

Meteorology

Airport Weather Instruments. Friez Weatherman is designed primarily for the airport dispatcher and gives instantaneous visual indication of wind velocity and direction, barometric pressure, and outdoor air temperature. Short description. Aero Digest, October, 1937, page 62, 4 illus.

Beaten by the Trade-Winds. Amelia Earhart Putnam and F. J. Noonan made their last flight in the face of strong and varying trade winds there. Calculations made from the wind speed, airplane speed and range show that there was only about 2–3 hours to spare for delays in storms and finding the island. Brief note. Bul. Am. Meteorological Soc., June-July, 1937, page 240.

Is This a Record? A height of almost 8 miles appears to have been reached by a sounding balloon dispatched by D. Brunt of the Meteorological Society. Instruments showed the height which had been reached and that the temperature was 97°F. below freezing. Brief reference. Aeroplane, September 29, 1937, page 377.

Lightning and Thunderstorms. "Do lightning bolts cause concussion waves that might shatter airships?" A. Eisler. Brief note included with reviews of literature on lightning and thunderstorms. Bul. Am. Meteorological Soc., June-July, 1937, page 250.

A Series of Radiometeorograph Soundings During February–April, 1937. C. Harmantas and D. P. Keily. Laboratory procedure and results of ascents made in joint program of Harvard Blue Hill Observatory and M.I.T. Instruments, calibrations, releasing, balloons and launchings, evaluation of recorded signals, comparison of results with those of airplane meteorograph, and notes on tube and battery tests in the laboratory and during flight. Monthly Weather Rev., June, 1937, pages 219–229, 8 illus., 1 table.

Aircraft Radio

Aero Radio Digest. Collins 17D ten-frequency aircraft transmitters recently completed for Braniff Airways, and the RCA AVT-12B crystal-controlled oscillator power amplifier transmitter for aircraft delivering to the antenna 50 watts for telephone emission or 90 watts for CW telegraphy. Descriptions. Aero Digest, October, 1937, page 60, 4 illus.

Aircraft Wireless. Three aerials in the Marconi radio equipment of the Caledonia include a trailing one for long-distance work, a fixed aerial running along the length of the machine and a rotatable frame. One transmitter is for CW only and for long-distance work, the other being for long distance and approach on the American side. Short description of equipment. Wireless World, July 16, 1937, page 61, 1 illus.

Essential Duplication. Special radio equipment for the D.H.86B for the North Sea service has independent power supplies. Short description. Flight, July 1, 1937, 3 illus.

Radio on the Empire Routes. J. H. Millar. Along British Empire routes, radio stations are being planned to provide two-way radio (telegraphy) for weather reports, direction finding (D.F.) and homing on medium waves, and two-way telegraphy on short waves principally for long distance communication. Existing Bellini-Tosi ground stations are being converted to Adcock. Marconi equipment for ground stations, flying boat equipment, direction finding, power supply, and equipment of the Cavalier used for Bermuda–New York commuting service are discussed. Aviation, October, 1937, pages 32–33, 75.

Radio System of American Airlines. H. W. Roberts. Possibility of carrying receiving antennas within the aileron structure to reduce drag, as well as the use of fabric-covered ailerons and those of dielectric materials are being considered. Outline of radio research being carried on by the airline, and a long description of the ground and flying equipment, ground stations and network, and the airline's radio maintenance system. Aero Digest, October, 1937, pages 36, 38, 71, 4 illus., 1 table.

R.C.A. Introduces New Radio. Models AVR-7D-E-F and G receivers for the itinerant flyer are completely new from power cable to antenna connection. Model AVT-7B transmitter is a 20-watt set, 100 per cent modulated on telephone transmission. Few details. Western Flying, October, 1937, page 30, 2 illus.

The Services. Automatic landing equipment developed at Wright Field and its operation are briefly reviewed and reference made to United Airlines system utilizing a Sperry automatic pilot coupled with a "bent-beam" type of radio blind-landing range. Aviation, October, 1937, pages 57–58, 4 illus.

Short-Wave Direction Finding. Marconi Type DFg.12 installation covering a wave range of 15–200 meters embodies the same principles which eliminated "night effect" from the medium-wave D/F. Few details of aerial system. Flight, July 8, 1937, page 61, 1 illus.

Telephony or – – – ? W. E. Crook. Comments on the question of using telephony or telegraphy for aircraft radio. Flight, July 8, 1937, page 62.

Too Good to Be True? Tests of the automatic landing system for aircraft at Wright Field. Editorial comment. U.S. Air Services, October 1937, page 9.

Aeronautical Industry and Production

Aircraft Production. Estimated and actual production of aircraft, and those available July 1, are shown for ten countries. An editorial points out that in Mr. Welch's statistics, compiled for Bendix, America leads the world in output and numerical strength and that her air strength is represented by 12,366 machines, a net gain of 695 aircraft. Flight, September 23, 1937, pages 314d, 303, 1 table.

New Manufacturers. Spencer-Larson, Tipton, Collier, and Lobil aircraft companies. Very brief references only. Aero Digest, October, 1937, pages 96–97.

Directory of the Manufacturers of Airport and Airline Equipment. Names of companies, addresses, executives and products. This issue also includes a directory of scheduled airway operators and airway map of the United States. Aero Digest, October, 1937, pages 75–92 and 72–73, 1 illus., 1 table.

Exports Up 90 Per Cent. China leads the list of nations importing American equipment in the first half of 1937. Netherlands was second, Russia third, and Argentine fourth. Value and number of aircraft, engines, parachutes, parts and accessories for 1936 and 1937 given. Western Flying, October, 1937, page 26, 1 table.

Pilots

Aviation Medicine. Commandant A. Langeron. Medico-physiological inspection services of the Armée de l'Air and requirements of physical aptitude for military aviators. Les Ailes, August 26, 1937, page 11.

The Four Winds. A Caproni III has been equipped as a flying laboratory for psychological study. Reports of experiments were given at the recent convention in Milan by specialists in medical and psychological aspects of flying. Very brief reference. Flight, October 14, 1937, page 377.

Air Forces

Technical Notes. Rumania has ordered thirty Italian Nardi 305 (150-hp. Fiat) airplanes and Chili has spent 38 million francs on aeronautical equipment in Italy. Brief reference. Les Ailes, September 16, 1937, page 9.

Twelve Savoia-Marchetti S-79 bimotored bombers (Gnôme-Rhône K-14 engines) have been ordered by the Rumanians. Les Ailes, August 26, 1937, page 6.

CANADA

Foreign News in Brief. Eighteen coast reconnaissance airplanes of the Blenheim type are to be built by Fairchild in Montreal for the Department of National Defense. Eighteen used planes have been bought for The Royal Canadian Air Force and 57 more fighting planes, as well as 27 training ships are being ordered. Fairchild order involves more than $1,250,000. Brief reference. Aero Digest, October, 1937, page 99.

FRANCE

Foreign Service News. A French squadron of large flying boats and the aircraft carrier "Commandante Teste" with squadrons of reconnaissance seaplanes and a squadron of bombers will patrol part of the Mediterranean. Brief reference to this and to proposed flights of 60 long-range military airplanes. Aeroplane, September 22, 1937, page 358.

GERMANY

Foreign Service News. Three squadrons of Ju.86, Do.17, and He.111 bombers and two squadrons of Dornier 17 and Heinkel 111 fighters, (total of 450 airplanes) took part in the German Air Force Display. Brief reference. Aeroplane, September 22, 1937, page 358.

GREAT BRITAIN

The Eighteenth Royal Air Force Display. C. M. McAlery. Long account of the Display and various maneuvers performed. Editorial preceding commends the mass formation especially. One page is devoted to the old wartime airplanes shown. Aeroplane, June 30, 1937, pages 790–798, 785–786, 13 illus.

Events described. Flight, July 1, 1937, pages 4–11, 11 illus.

The Four Winds. Five "jumping" autogiros on order and the Hafner gyroplane will be subjected to civil, naval, and army tests next year. Brief reference. Flight, September 30, 1937, page 330.

Air Ministry Contracts. British Air Ministry orders placed during July. List of equipment and companies but no reference to number or value. Aircraft Engineering, October, 1937, pages 277–278.

The Waziristan Campaign. Casualties suffered by British Government forces are already 221 killed and 601 wounded. Operations have cost about £1,000,000. Brief note. Aeroplane, October 13, 1937, page 439.

The Mediterranean Patrol. Two General Reconnaissance Squadrons armed with Short Singapore flying boats (four Rolls-Royce Kestrels) are to be based at Malta to take part in the anti-submarine patrol. Brief reference. Aeroplane, September 22, 1937, page 356.

The R.A.F. in the China Seas. Present strength of the R.A.F. units which are under the Far East Command with headquarters at Singapore. Brief note. Aeroplane, September 22, 1937, page 356.

ITALY

Italy's Maneuvers. Air Force units worked from bases widely distributed, and sometimes covered as much as 900 km. Short editorial discusses a semi-official report on maneuvers in Sicily. Flight, October 7, 1937, pages 344–345.

SWITZERLAND

Swiss Air Force is equipped with two-seater Fokker C-V-Es, single-seater Dewoitine D.27s, training D.H.5s (a Swiss-built type), Potez 25s, Fokker D.VIIs, Dewoitine D.26s, and Buecker Jungmeisters. Brief reference. Aeroplane, October 6, 1937, page 434.

U. S. S. R.

Battalions by Parachute. Most authorities agree that in European warfare the military value of dropping a number of armed parachutists cannot be high, though it might be very effective against semicivilized opponents. At recent maneuvers of the Russian army, 2200 parachutists armed with light machine guns were dropped in a single operation. Brief reference. Flight, September 30, 1937, page 327.

The Four Winds. Recently a Russian Army airplane was reported to have flown from Moscow to Kharkov, about 650 miles, at an average height of 5½ miles (29,500 ft.). Brief reference. Flight, September 23, 1937, page 307.

Air Warfare

The Four Winds. Mitsubishi 96 attack bomber (two 1000-hp. Kinsei engines, reported speed more than 400 km./hr.) is the aircraft chiefly used in bombing China. Known as the Japanese Blenheim it is said to have proved too fast for the Chinese defenders, among which are Curtiss Goshawk and Northrop machines. Raids were made at low altitude. Brief reference. Flight, October 14, 1937, page 377.

The Influence of Flying Boat Developments on Sea Power. E. E. Wilson. Possibilities of sixty-ton flying boats with a 4000-mile range and 8-ton military load for breaking or undertaking a blockade, and their advantages to China or Russia in preventing Japanese control of surface of the sea. U.S. Naval Inst. Proc., October, 1937, pages 1433–1444, 8 illus.